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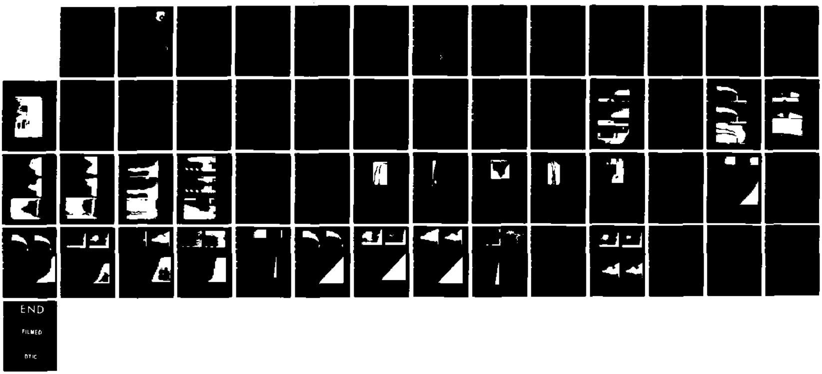

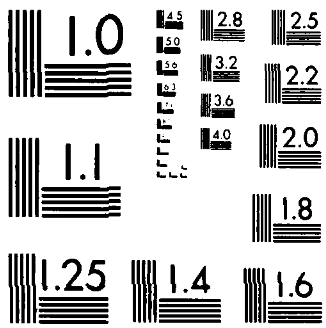

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DEMONSTRATE CAPABILITIES OF DIGITAL GRAPHICS SYSTEM TO OBTAIN QUANTITATIVE INFORMATION FROM FLOW VISUALIZATION DATA

Universal Energy Systems, Inc.
4401 Dayton-Xenia Road
Dayton, OH 45432

July 1985

Final Report for Period 1 October 1984 - 31 ~~July~~ MAY 1985

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This technical report has been reviewed and is approved for publication.

Edward Y. Hahn
Project Engineer

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FOR THE COMMANDER:

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The technical feasibility of using low cost digital graphics computer systems to obtain quantitative data from dynamic fluid simulations has been demonstrated. A computer graphics system is capable of capturing, digitizing, and color mapping of dynamic fluid flows. Such dynamic flow simulations are typical of test conditions found in a number of flow visualization test facilities. Utilizing injected dye fluids, it is possible to visually determine the relative dye concentrations or dispersion characteristics within recirculation and mixing zones of a test configuration.

The development of a complete dynamic fluid analysis system that includes a digital graphics system and basic image enhancement software would provide many engineering and design benefits to numerous simulation and flow visualization test facilities. A dynamic fluid analysis system could have great potential in commercial markets as an engineering or design tool in the areas of flow analysis, chemical processing, design of internal and external flow control devices, or as a teaching or training aid in fluid dynamics.

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PREFACE

This final report describes the research and development efforts conducted by Universal Energy Systems, Inc. on SBIR Phase I, Contract F33615-84-C-2481, to demonstrate the capability of a digital graphics computer system to obtain quantitative information from visual data obtained from dynamic fluid simulations.

This final report details the research and development studies that were performed to demonstrate the quantitative data acquistion and image enhancement capabilities of a low-cost computer graphics image capture and digitizing system. The SBIR Phase I effort was conducted to demonstrate the feasibility of utilizing computer graphics and image enhancement functions to develope a dynamic fluid analysis system. Such a system might have many commercial applications as an engineering tool in dynamic fluid simulation studies and in analytical computer modelling applications. Several hydrodynamic simulation flows about various bodies were conducted. Video images of resulting mixing flows of dye injection were captured, digitized, color mapped, and enhanced to obtain quantitative information regarding fluid mixing and concentration levels from purely visual information.

The efforts reported on herein were accomplished during the period 1 October 1984 through 31 May 1985 under the direction of Mr. Gary D. Streby, Project Engineer. This report was released 2 July 1985.

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SECTION I

INTRODUCTION

The objective of this SBIR Phase I effort was to demonstrate the capabilities of a computer graphics system to obtain quantitative data from dynamic fluid simulations. Dynamic fluid simulations have been utilized for many years in the study of aerodynamic and hydrodynamic investigations to determine flow and mixing characteristics of internal and external dynamic flows. Generally, dynamic fluid simulations provide only qualitative information regarding flow patterns and mixing zones. It is desirable to have the capability of obtaining quantitative data from these types of studies. It has been the aim of this investigation to demonstrate that a digital graphics image capture and digitizing system can yield quantitative information from only visual information.

A series of flow visualization tests were conducted using a small water flow channel and various objects in the flow stream to generate simulated fluid injections and mixing zones for investigation. Dye was injected at differen points in the flows for observation. Video images were recorded on video tape, captured by a graphics system, and digitized. The digitized images were then processed to yield gray-scale and colorized represe ations of the video images. The digitized images were then processed using various image enhancement routines to demonstrate the capability to extract quantitative information regarding injected fluid concentrations in the fluid stream and mixing zones.

The results of this Phase I effort have demonstrated that a digital graphics image capture and digitizing system and image enhancement

processing can provide quantitative information from flow visualization data. Digitizing and color mapping of visual images yields data regarding the relative concentration of injected fluids in a dynamic fluid stream. These images can be analyzed quickly and easily when various colors represent different concentrations in a fluid stream. The image enhancement of the digitized images improves the quality of the captured images and also yields additional quantitative information.

With the availability of new computer graphics systems that have improved capabilities and operating speeds, it would be feasible and worthwhile to develope a dedicated computer graphics and image enhancement system designed specifically for dynamic fluid flow analysis and computer modelling development applications. The development of this product would yield a very valuable engineering tool that would have applications in both Government and industry.

SECTION II

FLOW SIMULATION APPARATUS

In order to evaluate the capabilities of a computer graphics system to analyze dynamic fluid simulations, it was necessary to fabricate a small water flow channel in which simulation flows could be conducted. A small blow down water flow channel was designed and fabricated that allowed controlled experiments to be conducted of various mixing flows about different shaped bodies or through a mixing chamber. A schematic diagram of the flow channel is presented in Figure 1 and a photograph of the flow channel and video camera is presented in Figure 2.

Various flow bodies and configurations were tested in the flow channel to observe the mixing characteristics of injected dye. Test models consisted of a injection probe, wedge, centerbody, and an airfoil. A configuration of a dual flow mixing chamber was also fabricated and tested to simulate a simplified combustion chamber. Drawings of the test configurations that were tested are shown in Figure

The water flow channel had a 2 inch by 4 inch cross section and could flow water at velocities up to 4.3 ft. sec. with a run time of approximately 3.0 seconds at maximum velocity. For most of the dye injection studies that were conducted, the flow rate through the test section was approximately 0.75 ft./sec.. This gave run times on the order of 15 seconds. The Reynolds Number for these flows was 15,450 based on the hydraulic diameter of the cross section. This gave fully turbulent flow throughout the test section.

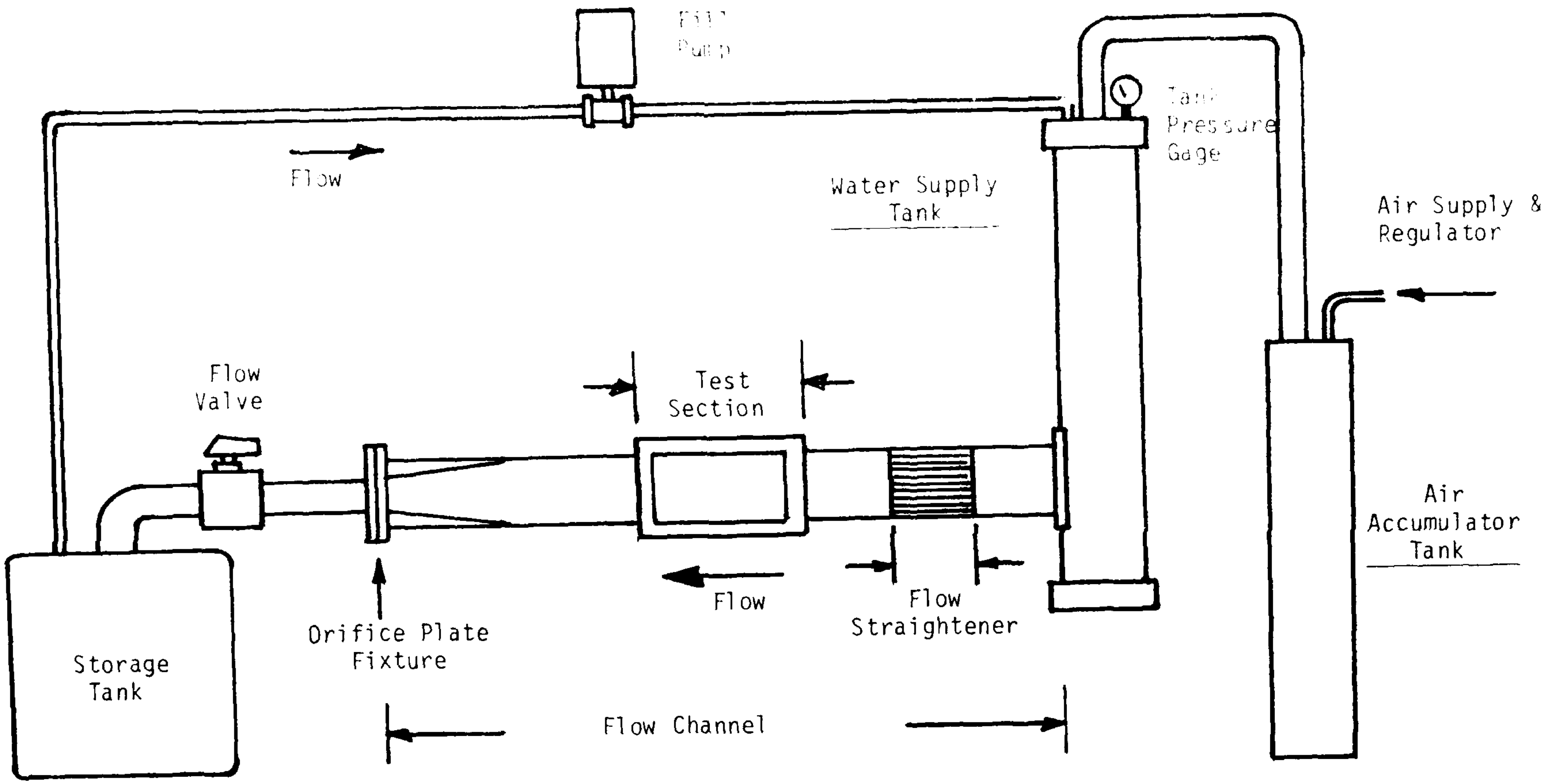


Figure 1. WATER FLOW CHANNEL HARDWARE

Figure 2: Photograph of Flow Channel and Video Camera

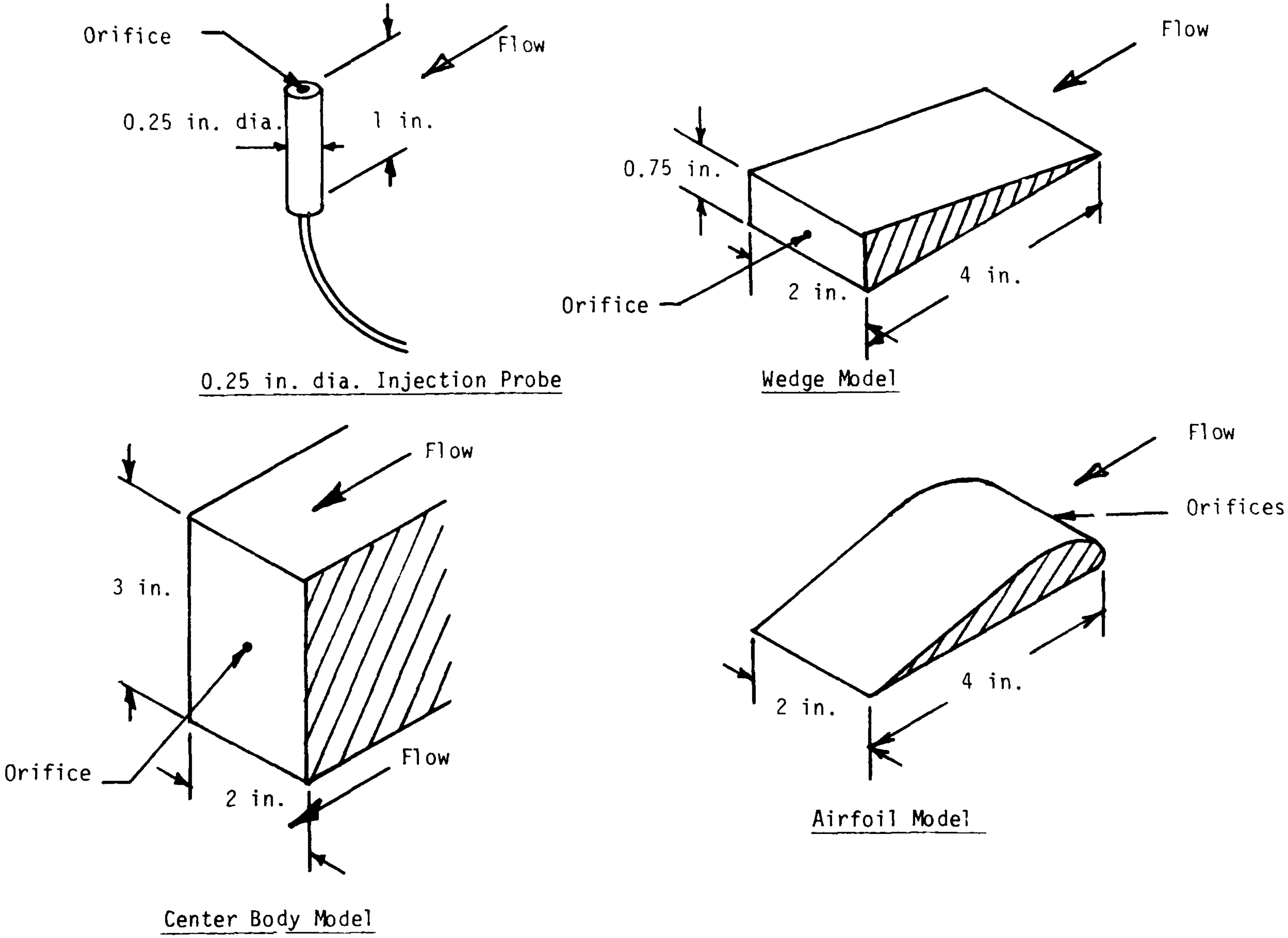
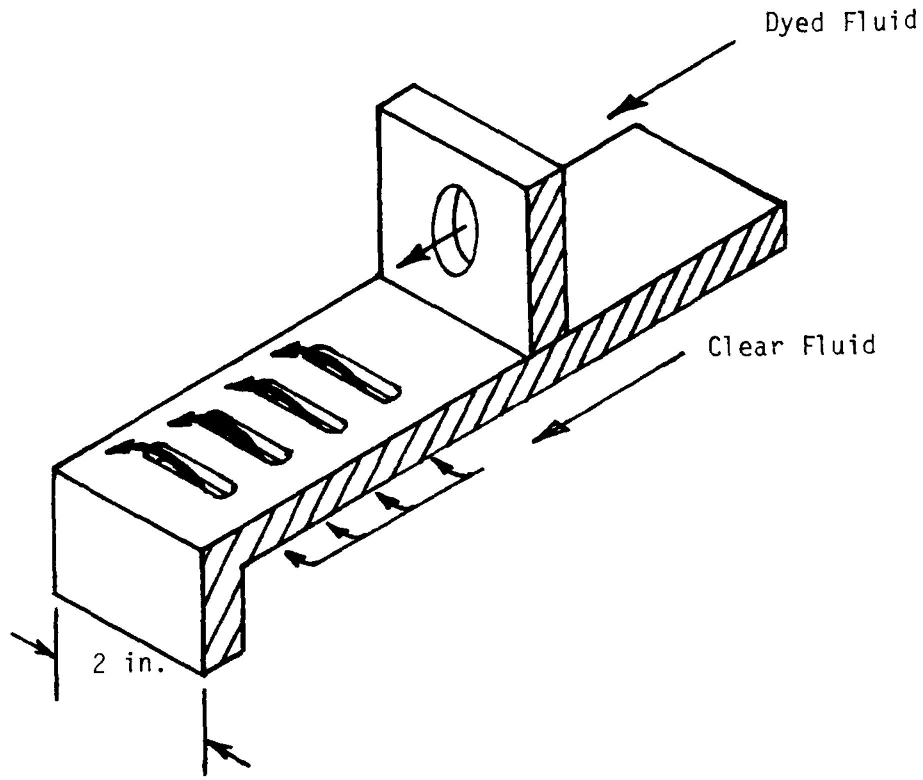


Figure 3. TEST CONFIGURATIONS



Dual Mixing Flow Model

Figure 3. TEST CONFIGURATIONS (Conclusion)

SECTION III

COMPUTER GRAPHICS IMAGE PROCESSING SYSTEM

The computer graphics and image processing system, utilized in the SBIR Phase I effort, provided the capability to view, capture, digitize, and color map visual images of dynamic fluid simulation flows. With the information obtained from digitzed and color mapped images preliminary image enhancements could be accomplished to demonstrate the capability to derive qualitative and quantitative information from visual data.

3.1 VIDEO RECORDING AND DISPLAY EQUIPMENT

In order to provide the necessary input to the digitial graphics system, a standard composite video signal had to be provided. A Panasonic WV-1800 High Resolution B&W Video Camera with a F12.5 wide angle lens was used to view the test articles and provide the video signal to a Panasonic PV-1530 Video Recorder and the computer graphics system. The video recorder was utilized to store visual test data for processing and playback. A Panasonic CTF-1495 RGB High Resolution Video Monitor was used to display the camera or recorder video signals as well as to display the computer graphics RGB video output. Figure 4 shows a schematic of the video recording and display equipment as utilized with the water flow channel.

3.2 COMPUTER AND VISUAL GRAPHICS SYSTEM

The computer graphics image capture and processing system used in this Phase I effort was a Digital Graphics Systems, Inc. CAT-200 system. This system consisted of four S-100 graphics boards that operated on an S-100 computer bus and used Z-80 microprocessor based software for

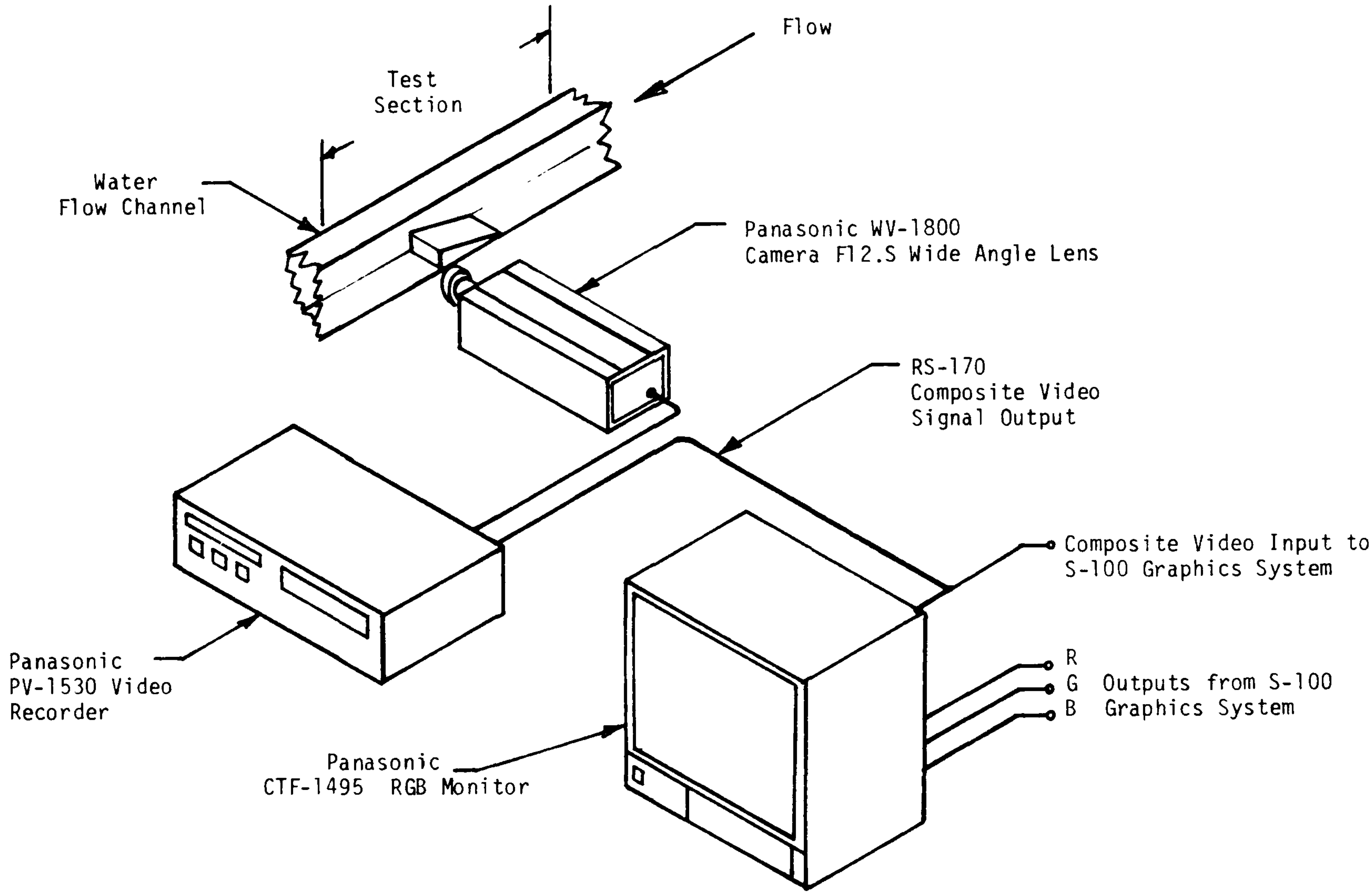


Figure 4. VIDEO RECORDING AND DISPLAY EQUIPMENT SCHEMATIC

control of the graphic system functions. The visual graphics system was capable of video frame capture, digitization, and color mapping. The graphics system could display the digitzed images in three resolutions that varied in the number of horizontal and vertical pixels (picture elements) and the resolution per pixel. Resolutions of 512H X 484V with 2 bits per pixel and 512H X 242V with 4 bits per pixel. Resolution of 256H X 242V with 8 bits per pixel was not available because of software problems. The computer system was a Teletek Systemaster S-100 single board computer with a 4 Meghz Z-80 microprocessor on a 10-slot motherboard controlled by a Freedom 100 terminal. The S-100 system utilized the Digital Research CPM-80 operating system with Microsoft MBASIC language. This system was used for this effort when the Government provided computer system could not be obtained in a time frame that would fit the schedule of this Phase I effort.

The assemble language software package was designed to be linked to a higher level language for operation with BASIC programs. When linkage to the higher level language was accomplished, the various graphics functions could be easily called from a BASIC program. Graphic functions performed video frame grabbing, digitizing, graphic screen outputs, and image transfer functions. Other functions were available to provide grayscale or color information at any set of coordinates on the image screen. Because of hardware or software difficulties that could not be resolved in the time frame of this effort, the values of individual pixels could not be obtained directly from the computer system. Data on pixel values had to be obtained from the visual image themselves. This information was then utilized as input to perform the image processing of the flow visualization images.

3.3 IMAGE PROCESSING SYSTEM

The image processing of flow visualization test data was performed on an Apple IIe microcomputer with Dynacomp Digital Image Processing software. This software was capable of performing most of the fundemental image processing routines but had a resolution of only 32V X 64H. The resolution was however sufficient to demonstrate the capabilities of deriving flow characteristic and fluid concentration information using image processing techniques.

SECTION IV

TEST PROCEDURE

Efforts during the Phase I program were primarily directed at demonstrating the capabilities of a computer graphics system to derive quantitative information from typical flow visualization data. To achieve this goal, tests were conducted with water as the simulation fluid to observe the mixing and flow characteristics about various shapes when a dyed fluid is injected into the fluid stream. A number of different flow situations were devised to try and obtain serveral flow conditions. Dye injections were made directly into a moving fluid stream: dye was injected into recirculation zones of various shapes; and dyed fluid was injected into a mixing chamber. It was felt that these tests represented the typical turbulent mixing characteristics of many dynamic fluid simulations presently being studied or analyzed.

In each test case the test section of the water flow channel would be back lighted through white optical plastic to diffuse the light source. The light source was a 60 watt incandescent lamp in a reflective holder. The test section was viewed with the video camera and examined through the computer graphics system so lighting could be adjusted to obtain a uniform background lighting. The background lighting was accomplished with water and the test configuration in the test section. Each test configuration was drilled with small (0.063 in. dia.) orifices and passages for the injection of dye from the model. The orifice locations on the various models are shown in the sketches in Figure 3. The dye passages were plumbed from the model to the outside of the test

chamber were dye was injected using a large syringe. The dye used for test purposes was a Jet Black food coloring. The dye was composed of sugar, propylene glycol, glycerine, and color pigments. The paste dye was diluted with water to make a liquid dye with a concentration of 4.27 percent dye to water by volume. This concentration produced the darkest (black) gray-level on the graphics system. The diffused backlighting and clear water in the test section gave the white gray-level. The gray-level shades between white and black represented the concentration levels between the two conditions. It should be noted that the light intensity viewed by the video camera was the result of the light passing through the depth of the test section. Therefore, the resultant light intensity at any single point represented the resultant dye concentration across the test section. Variations of dye concentrations across the test could not be determined unless the flows were also observed in the vertical direction. For experiments in this study observations were only made horizontally through the test section.

To conduct a test run, the system would be completely filled with water with the control valve shut. After filling with water, the air accumulator tank would be pressurized to the proper test condition pressure and the control valve opened. With the control valve opened the water would flow through the flow channel at a rate determined by the total air pressure in the system and the orifice plates mounted downstream of the test section. After the flow was established in the test section, dye would be injected into the model for introduction into the fluid stream. Typically the time of each test run was on the order of ten to fifteen seconds. For each test run a video image would be recorded on video tape for later replay and computer graphics processing.

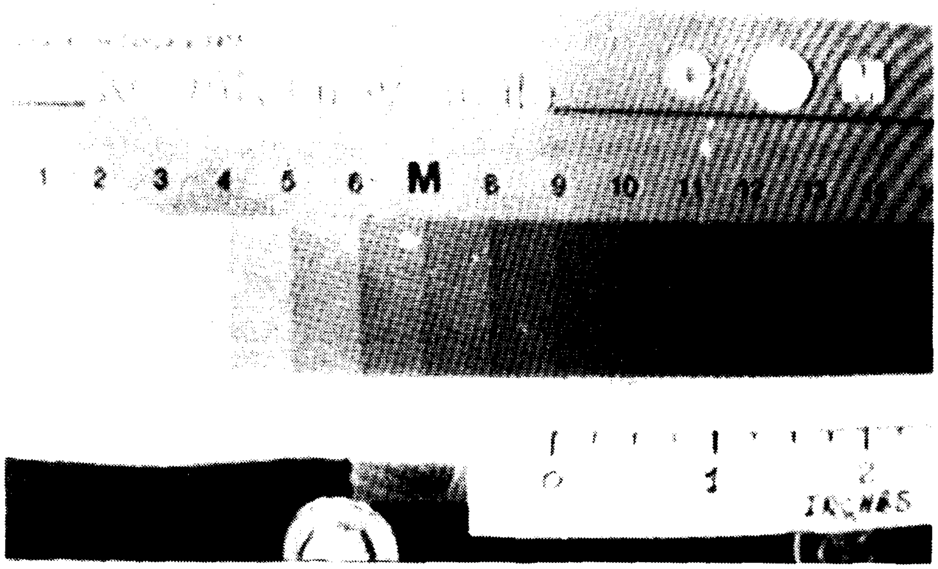
SECTION V

TEST RESULTS

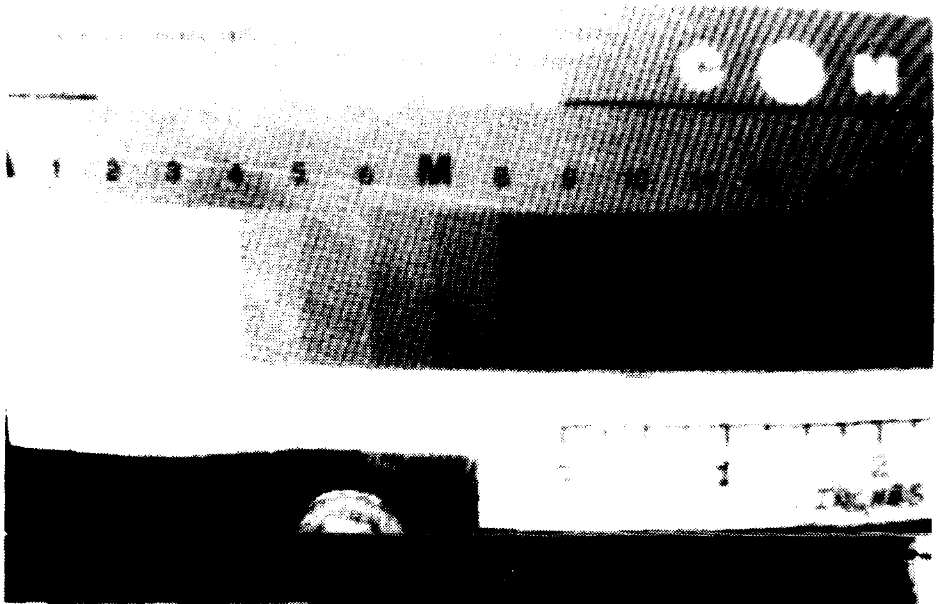
There were two primary objectives in the Phase I effort. The first objective was to demonstrate the capabilities of a low-cost computer graphics system at obtaining quantitative information from typical dynamic fluid flow simulation visual data. The second objective was to demonstrate the analysis capabilities of visual image enhancement processing. These results needed to be successfully demonstrated before efforts can be initiated to further development of a prototype dynamics fluid flow analysis system as a possible commercial product. Presented herein are the results that were obtained during the Phase I program.

5.1 RESULTS OF COMPUTER GRAPHICS PROCESSING

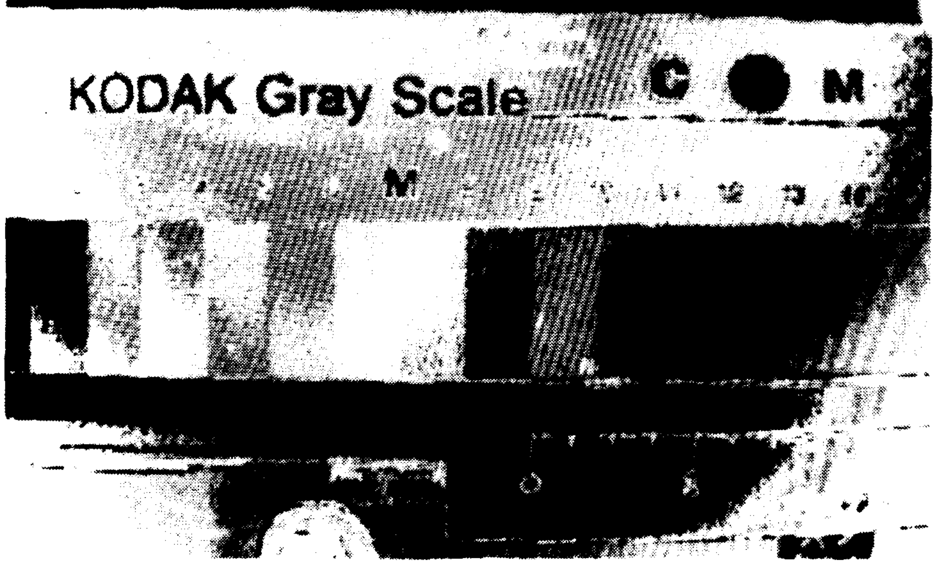
After flow visualization test were conducted, the recorded test data was visually examined by the three techniques that are available using the computer graphics system. First, the visual data was observed as a normal video B&W signal as viewed in the normal playback mode of a videotape recorder. Secondly, the visual data could be viewed through the graphics system as digitized B&W images showing the various digitized gray-levels. The third method was to observe the visual data as processed by the computer graphics system using a color map lookup table. These images were the same as the digitized images except that each gray-level was replaced by a color. The data presented here had 4 bits resolution per pixel which yields sixteen different gray-levels or colors. Figure 5 shows a 16 gray-level scale as viewed on the display monitor. Pictures were taken directly off the screen of the display



Direct Video Image
Gray-Level Scale



Digitized Video Image
Gray-Level Scale

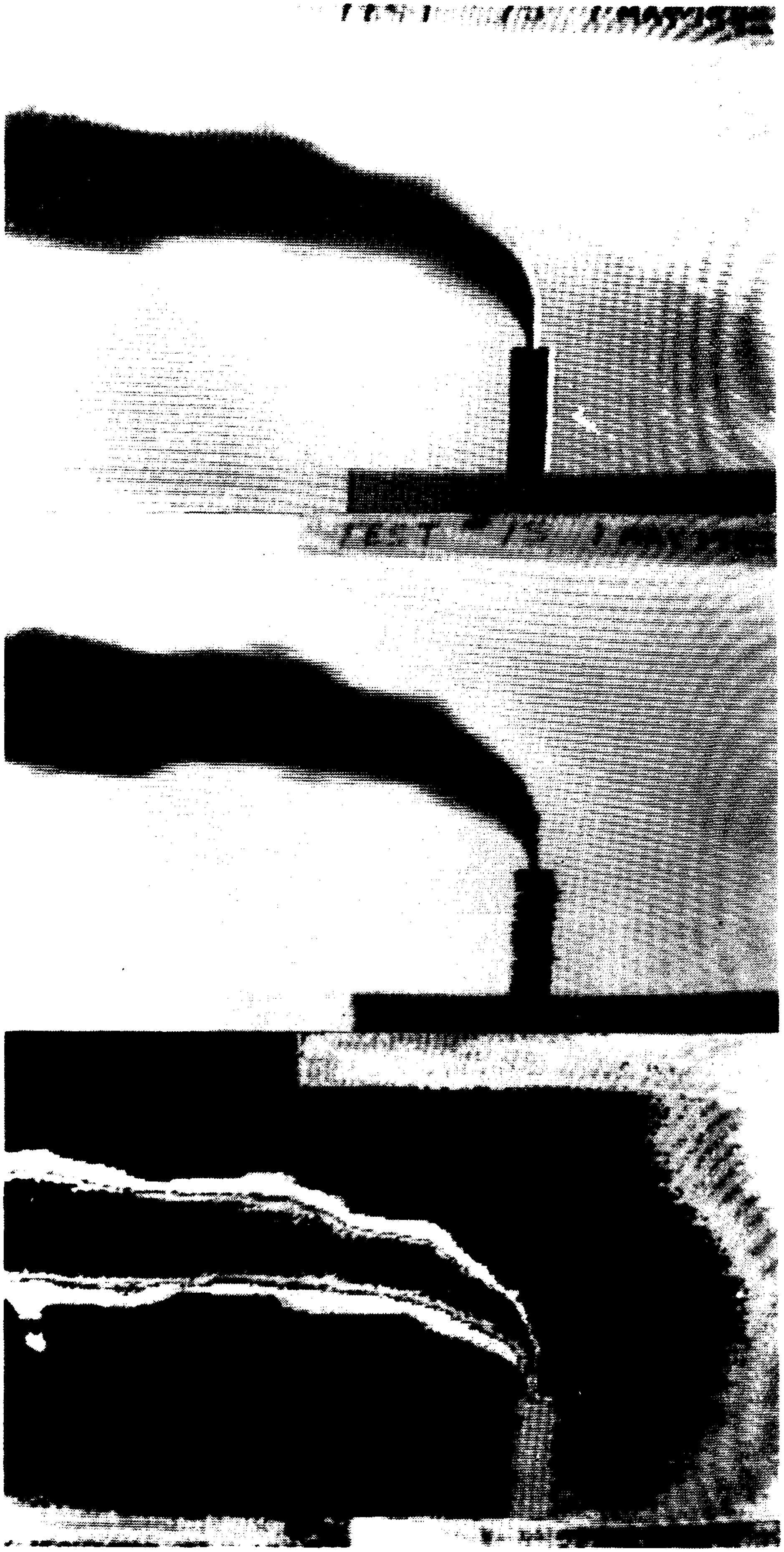


Color-Mapped
Video Image
Gray-Level
Scale

Figure 5. COMPARISONS OF VIDEO, DIGITIZED, AND COLOR-MAPPED IMAGES OF GRAY-LEVEL SCALE

monitor. The top picture shows the normal video signal, the middle picture shows the digitized RGB signal, and the bottom picture shows the results of using the color map on the digitized image. Figures 6 through 10 are the same results for the four different models that were tested. Figure 6 is the image of dye injection from a vertical 1/4 inch diameter injection probe perpendicular to the fluid stream. Figure 7 shows the mixing zone behind a wedge model with dye injected on the downstream face of the wedge. Figures 8 and 9 are of mixing and recirculation zones behind a large centerbody model. The flow was only from the top and bottom with dye injected at the center of the body. Figure 8 is the flow very shortly after dye injection. Figure 9 is the flow several seconds later as the dye is being dispersed in the recirculation region. Figure 10 shows the dye flow over the trailing edge of an airfoil model. Dye was injected at the nose on both top and bottom surfaces. Figure 11 shows the mixing flows of clear and dyed fluids in a simplified combustor configuration. The dyed fluid enters through an orifice in the top portion of the chamber while the bottom clear fluid enters the chamber through angled slots.

The results showed that with the digitizing capability, available with the computer graphics system, additional qualitative information can be obtained easily and quickly from visual data. As can be seen, the digitized B&W images have more contrast and the various gray-levels are detailed. By quantitizing the gray-levels in the image, information can be obtained that would not be available from the normal video image. The B&W digitized image is even more enhanced and details visualized when a color map is applied to the digitized image. Flow patterns and mixing



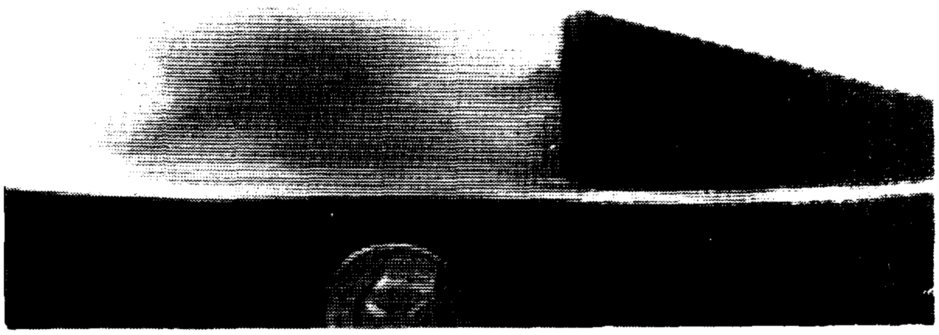
Direct Video Image
Injection Probe

Digitized Video Image
Injection Probe

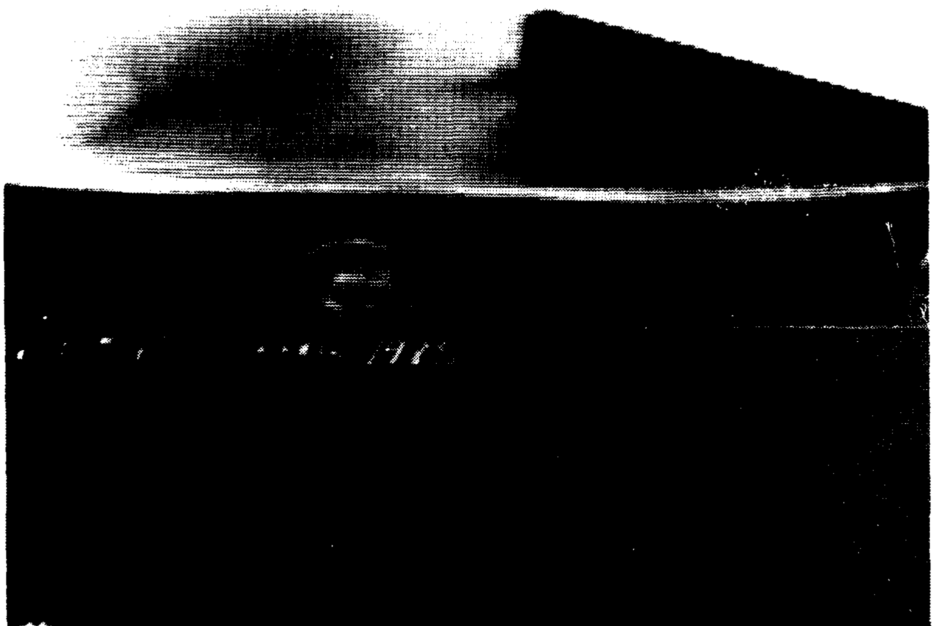
Color-Mapped
Video Image
Injection Probe

Figure 6. CCMPARISONS OF VIDEC, DIGITIZED, AND COLOR-MAPPED IMAGES OF 1/4 INCH DIAMETER INJECTICN PROBE

Direct Video Image
Wedge Model Flow



Digitized Video Image
Wedge Model Flow



Color-Mapped
Video Image
Wedge Model

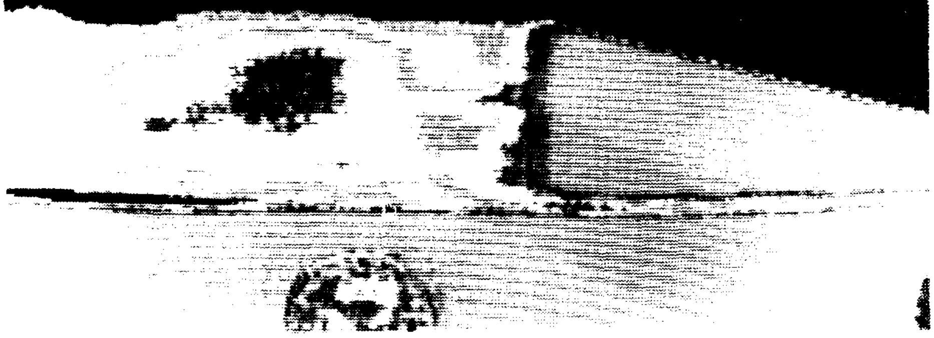
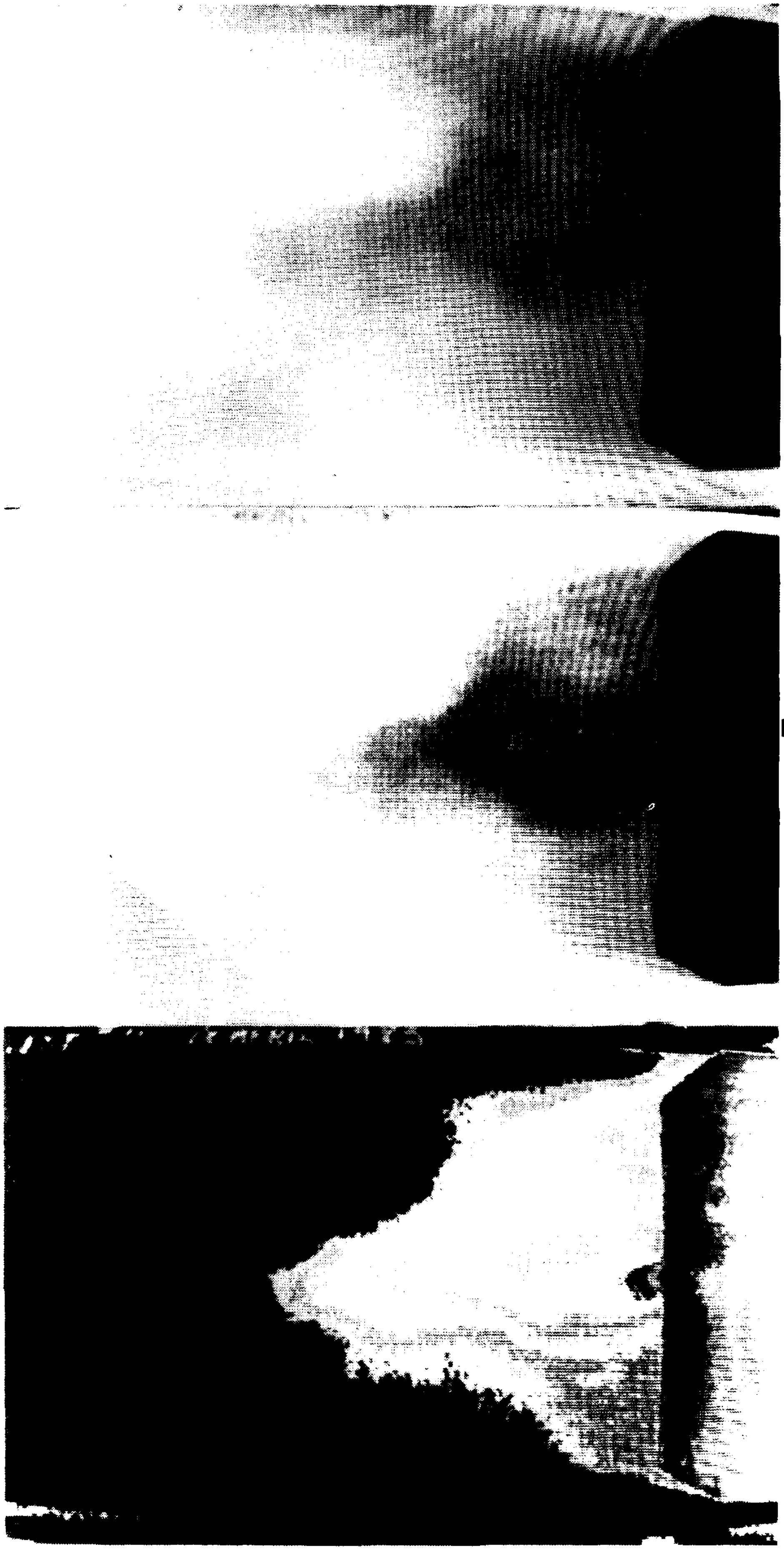


Figure 7. COMPARISONS OF VIDEC, DIGITIZED, AND COLOR-MAPPED IMAGES OF WEDGE MODEL FLOW

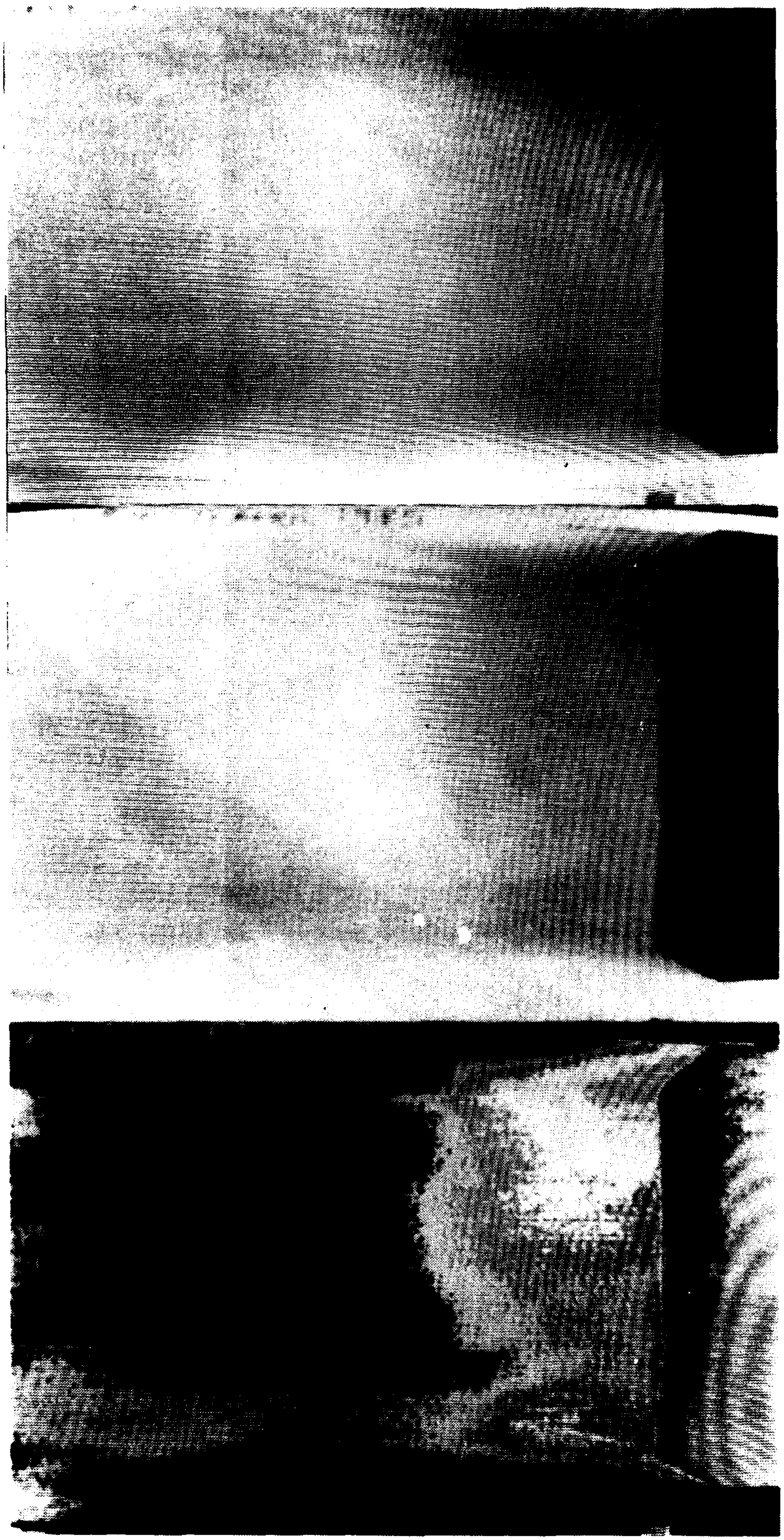


Direct Video Image
Centerbody

Digitized Video Image
Centerbody

Color-Mapped
Video Image
Centerbody

Figure 8. COMPARISONS OF VIDEO, DIGITIZED, AND COLOR-MAPPED IMAGES OF CENTERBODY MODEL SHORTLY AFTER DYE INJECTION

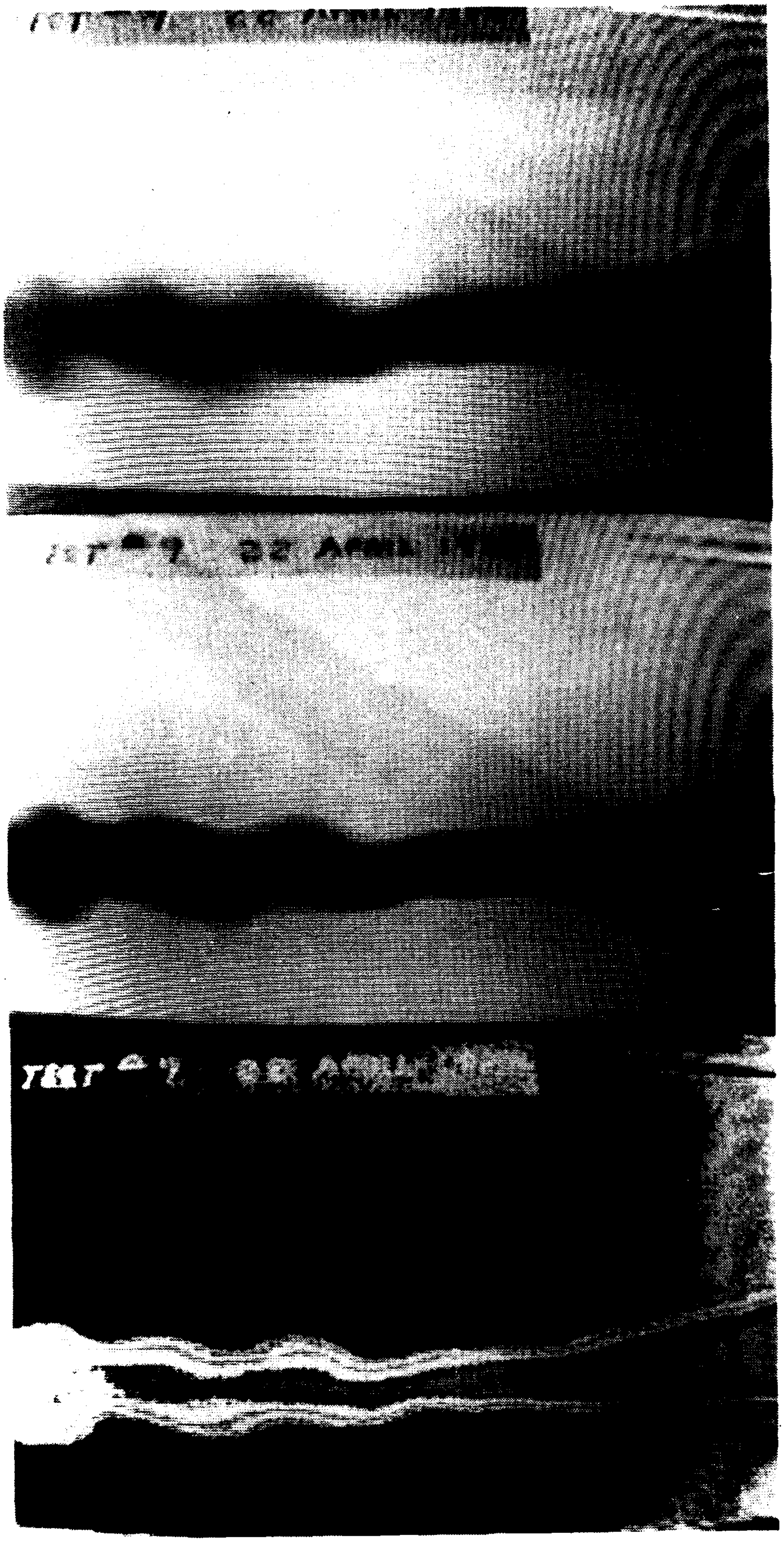


Direct Video Image
Centerbody

Digitized Video Image
Centerbody

Color-Mapped
Video Image
Centerbody

Figure 9. COMPARISONS OF VIDEO, DIGITIZED, AND COLOR-MAPPED IMAGES OF CENTERBODY MODEL DURING DYE DISPERSION

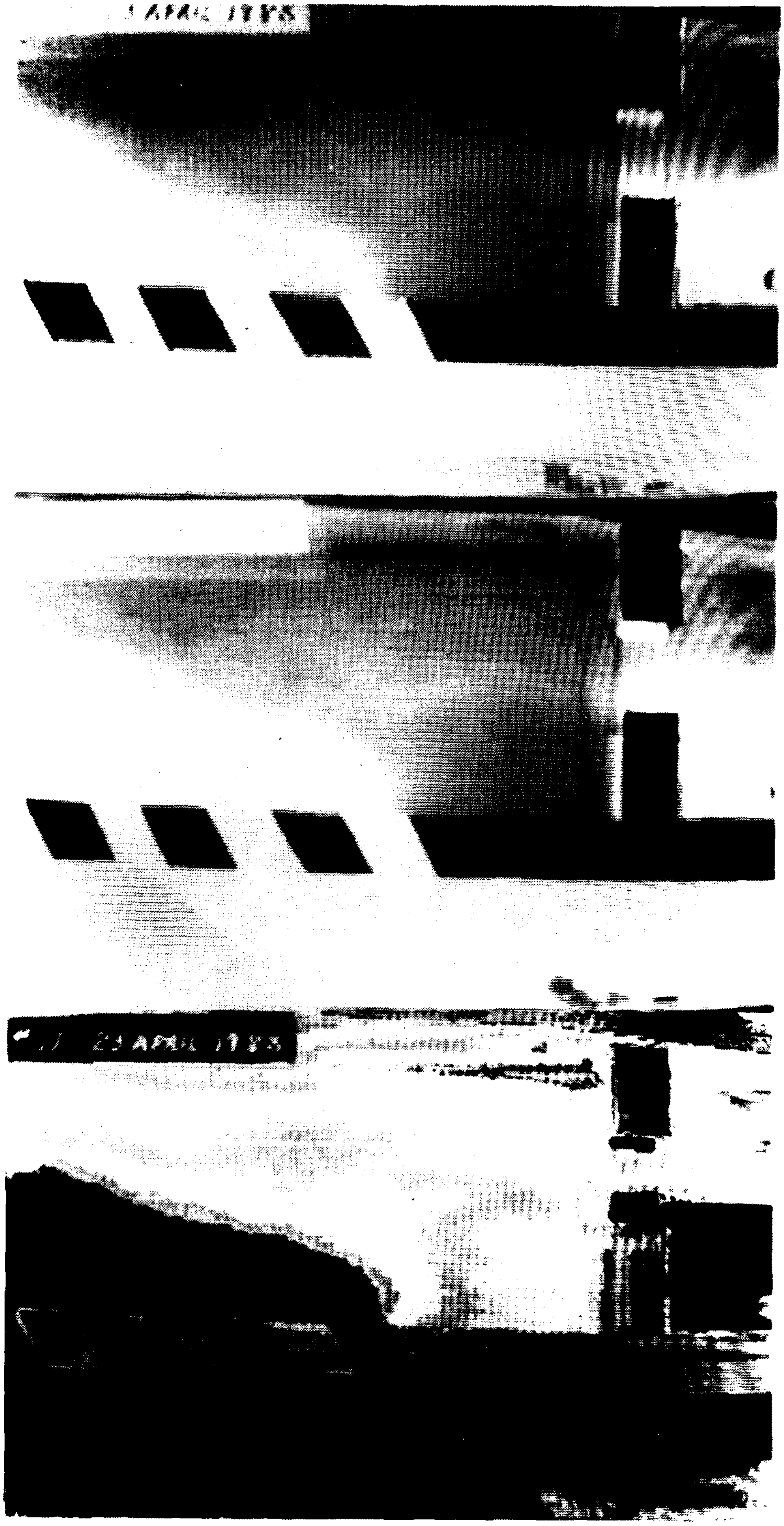


Direct Video Image
Airfoil

Digitized Video Image
Airfoil

Color-Mapped
Video Image
Airfoil

Figure 10. COMPARISONS OF VIDEO, DIGITIZED, AND COLOR-MAPPED IMAGES OF AIRFOIL MODEL



Direct Video Image Combustor

Digitized Video Image Combustor

Color-Mapped Video Image Combustor

Figure 11. COMPARISONS OF VIDEO, DIGITIZED, AND COLOR-MAPPED IMAGES OF COMBUSTOR MODEL

zones are more easily defined, detailed, and quantitative information can be obtained directly. When the concentraton of injected fluids is related to the color or gray-level scales, fluid concentration data can be obtained directly by observing the gray-level or color in the processed image. Figure 12 is a plot of dye concentration versus gray-level scale for the dye which was used as the injected fluid.

Presented in Figures 13, 14, 15, 16, and 17 are the results of obtaining injected fluid concentrations in various fluid flows and mixing zones. Each figure shows the flow image that was processed and the cross section at which concentrations were determined. For each image cross section, a plot is presented that gives the variation in dye concentration for the cross section. Plots were obtained by appling the equation of the dye concentration curve to the digitized image gray-level values. The relative dye concentrations of the various gray-levels can be quickly and easily determined. Also, the concentration within different mixing zones is detailed.

5.2 IMAGE PROCESSING RESULTS

To demonstrate the capabilities of image enhancement to obtain quantitative information, several of the digitized and color mapped images were processed using a low-resolution image processing program. Because of technical difficulties with the graphics system that could not be resolved within a reasonable amount of time, several of the graphic images were transfered and processed on a low-resolution Apple IIe system. Data was transposed from the color mapped graphic images to generate images in the Apple IIe system. After the data was entered into the Apple IIe system several image enhancement routines were performed on

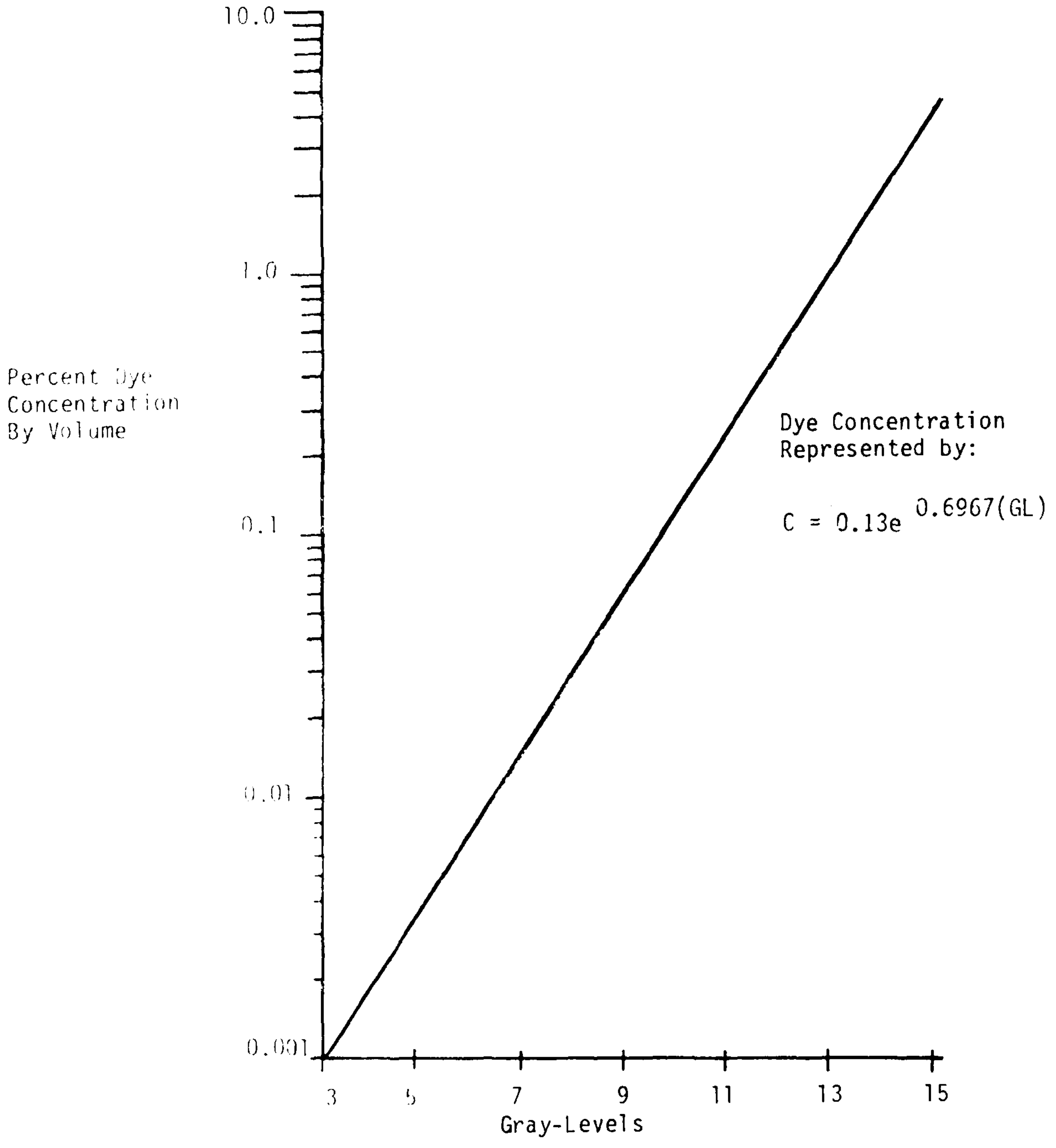
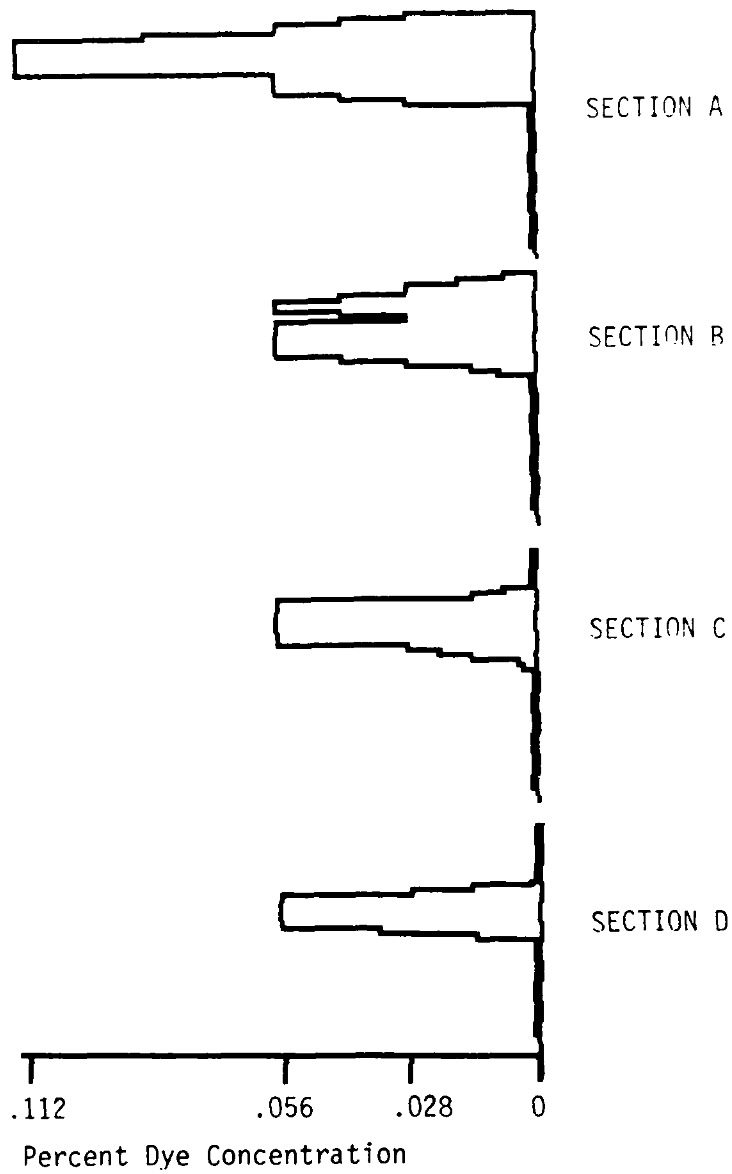
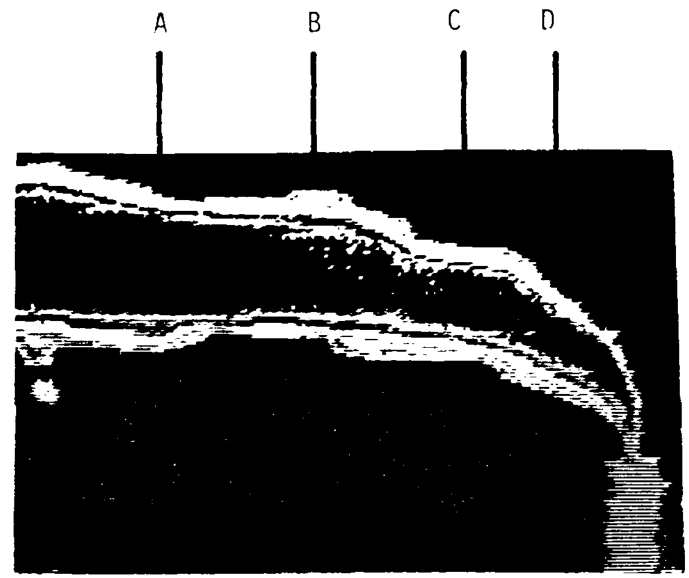


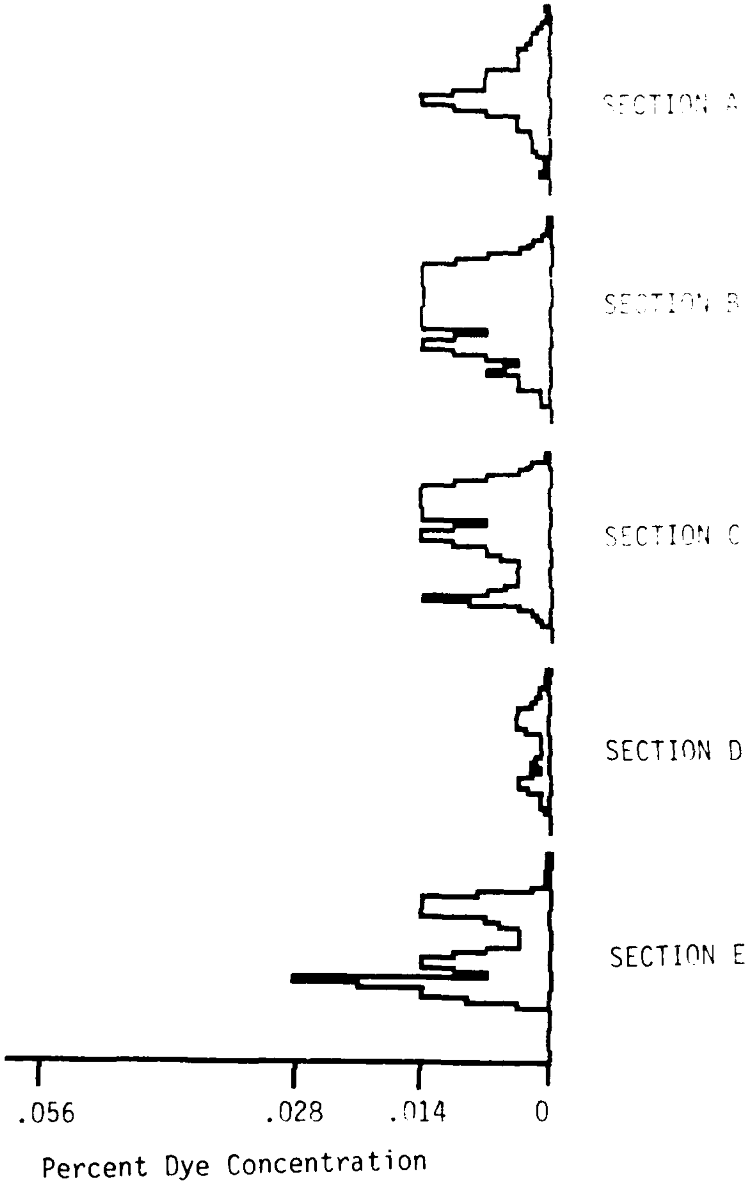
Figure 12. PERCENT DYE CONCENTRATION VERSUS GRAY-LEVELS

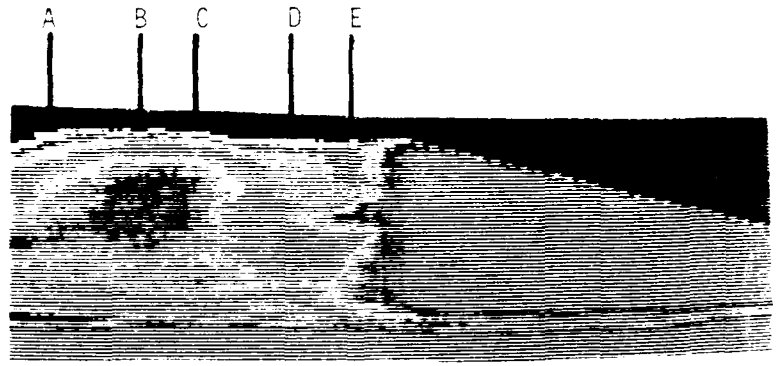




1/4 Inch Diameter Injection Probe Image

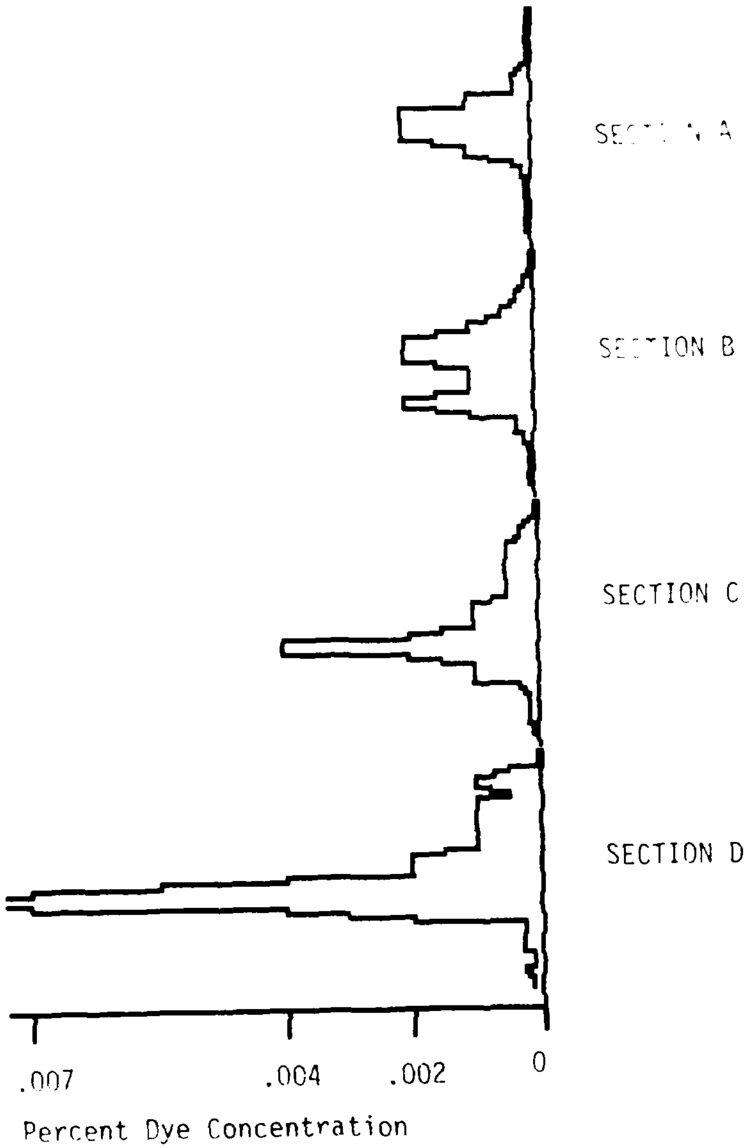
Figure 13. DYE CONCENTRATION PROFILES OF INJECTION PROBE FLOW

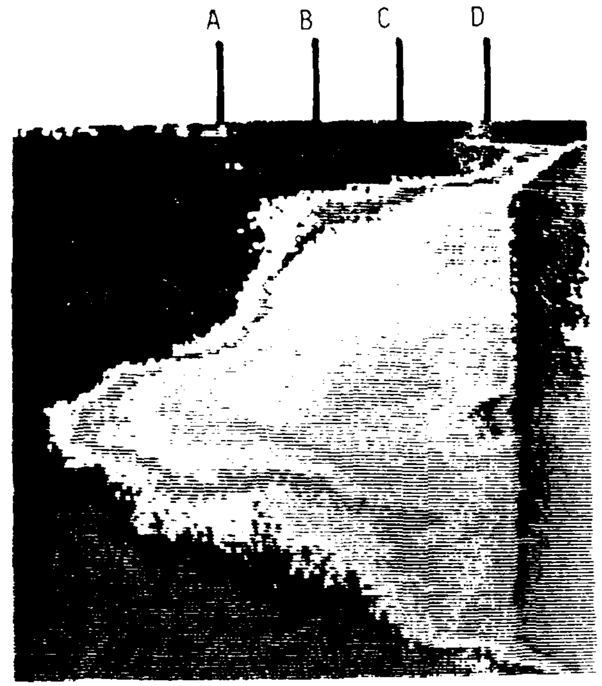




Wedge Model Flow Image

Figure 14. DYE CONCENTRATION PROFILES OF WEDGE MODEL FLOW





Centerbody Model Flow Image

Figure 15. DYE CONCENTRATION PROFILES OF CENTERBODY MODEL FLOW

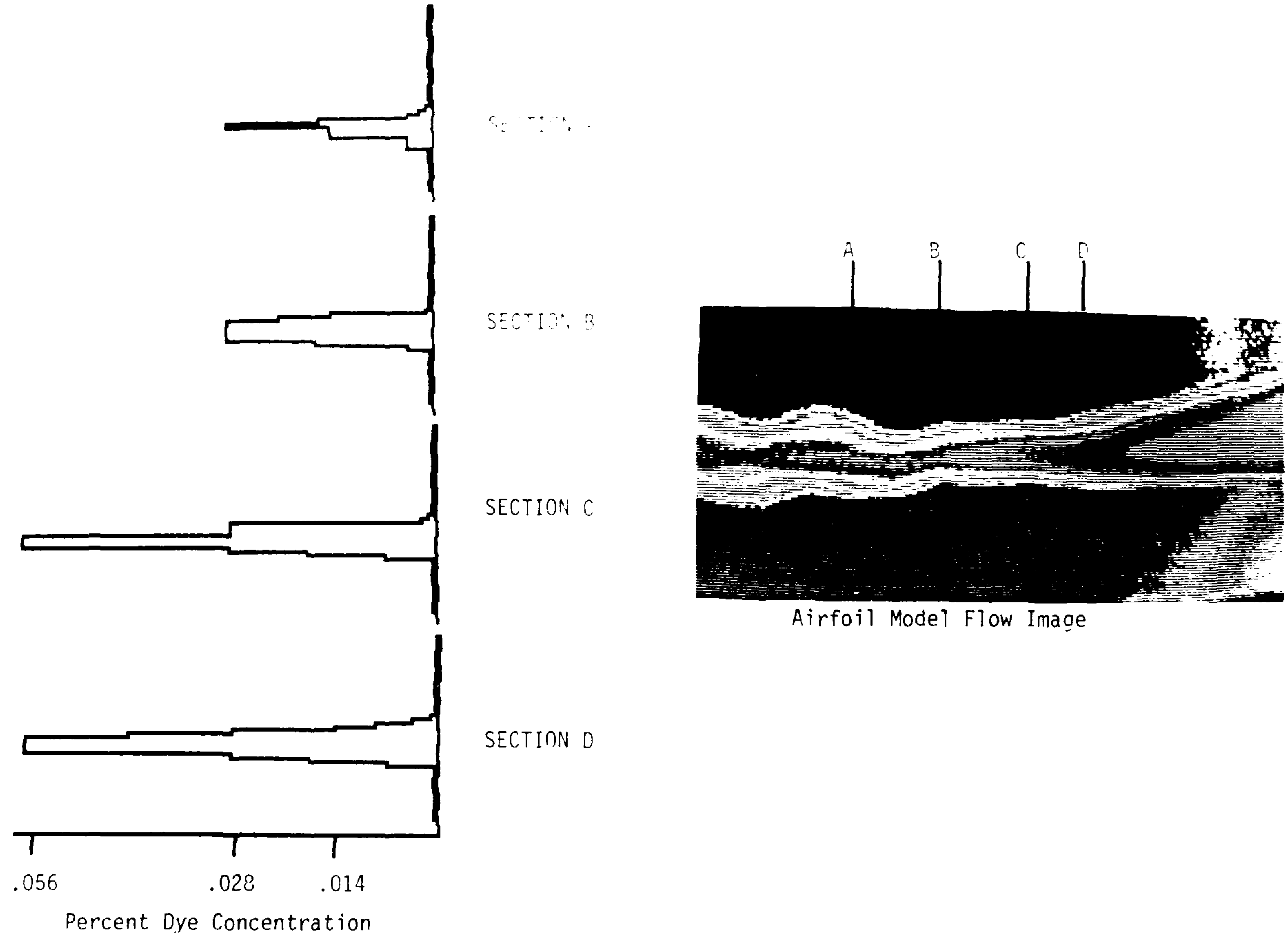


Figure 16. DYE CONCENTRATION PROFILES OF AIRFOIL MODEL FLOW

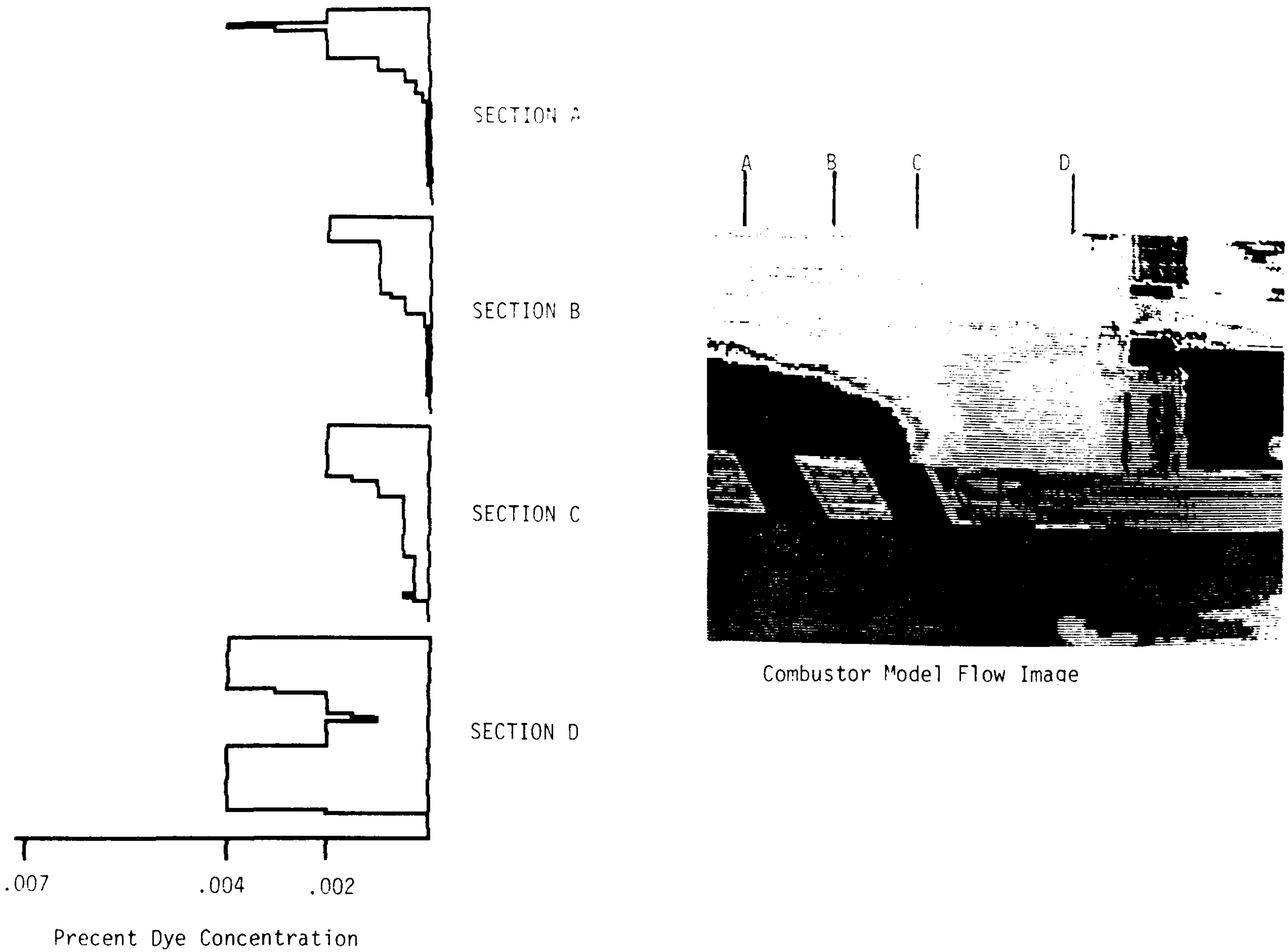


Figure 17. DYE CONCENTRATION PROFILES OF COMBUSTOR MODEL FLOW

each image. It should be noted that the resolution of the Apple IIe software was 64H X 32V with seven gray-levels. The processed images do not have the detail of the original images but they do demonstrate the unique capabilities that can be achieved with image processing.

The image processing software was capable of performing most of the basic image processing routines that have been utilized to derive information from visual data. The software included histogram correction, segmentation and logarithmic correction.

Histogram correction is a routine whereby the histogram of an image is integrated to produce a corrected histogram which is used to reproduce the image. Segmentation is a routine that converts the image lookup table to values specified in the original gray-scale. This routine highlights only certain values or range of values in the image while all other values are zero. The logarithmic correction routine converts a linear lookup table to a logarithmic function that can be varied. This routine can enhance low or high intensity levels depending upon the logarithmic function used.

Presented here are the low-resolution processed images of the gray-level scale, injection probe, wedge, centerbody, airfoil, and combustor model flow visualization data. Figure 18 shows the original and processed images of the gray-level scale as shown in Figure 5. These processed images were obtained using the histogram correction routine. the histogram of the original data and the conversion plot for the processed image are presented at the bottom of the figure. The histogram correction defines more evenly the gray-levels from the original data.

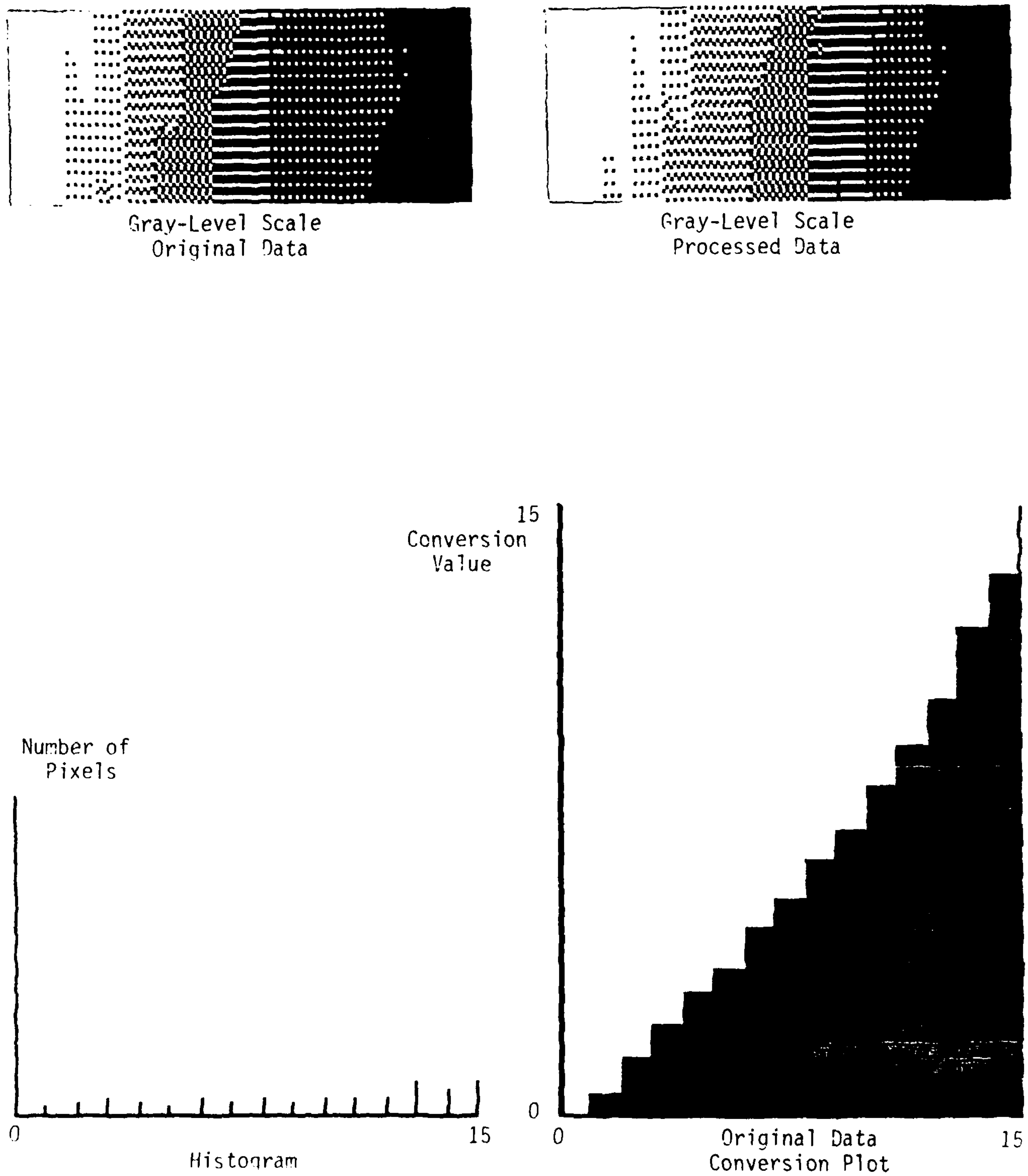


Figure 18. HISTOGRAM CORRECTION OF GRAY-LEVEL SCALE IMAGE

Figures 19 thru 22 show the results of using the histogram correction routine on the digitzed color-mapped images of the test flows shown in Figures 6, 7, 8, 10, and 11 respectively.

Figures 23 thru 27 show how the segmentation routine is utilized to define a particular quanity in the visual data. Only the value of designated gray-levels are reproduced in the processed image. Shown in these figures are the original and processed images of the test flows for a range of gray-level values using the segmentation routine. This routine could easily be utilized to quantize fluid concentration values within a dynamic fluid region. These results are also for the digitized color-mapped images presented in Figures 5 thru 11. In Figure 28 the logarithmic processing routine is demonstrated. This is another example of how additional information can be derived from visual data. The figure shows a plot of the conversion curve used to process the image and the processed images. These are for the digitized color-mapped images shown in Figures 7, and 8 respectively.

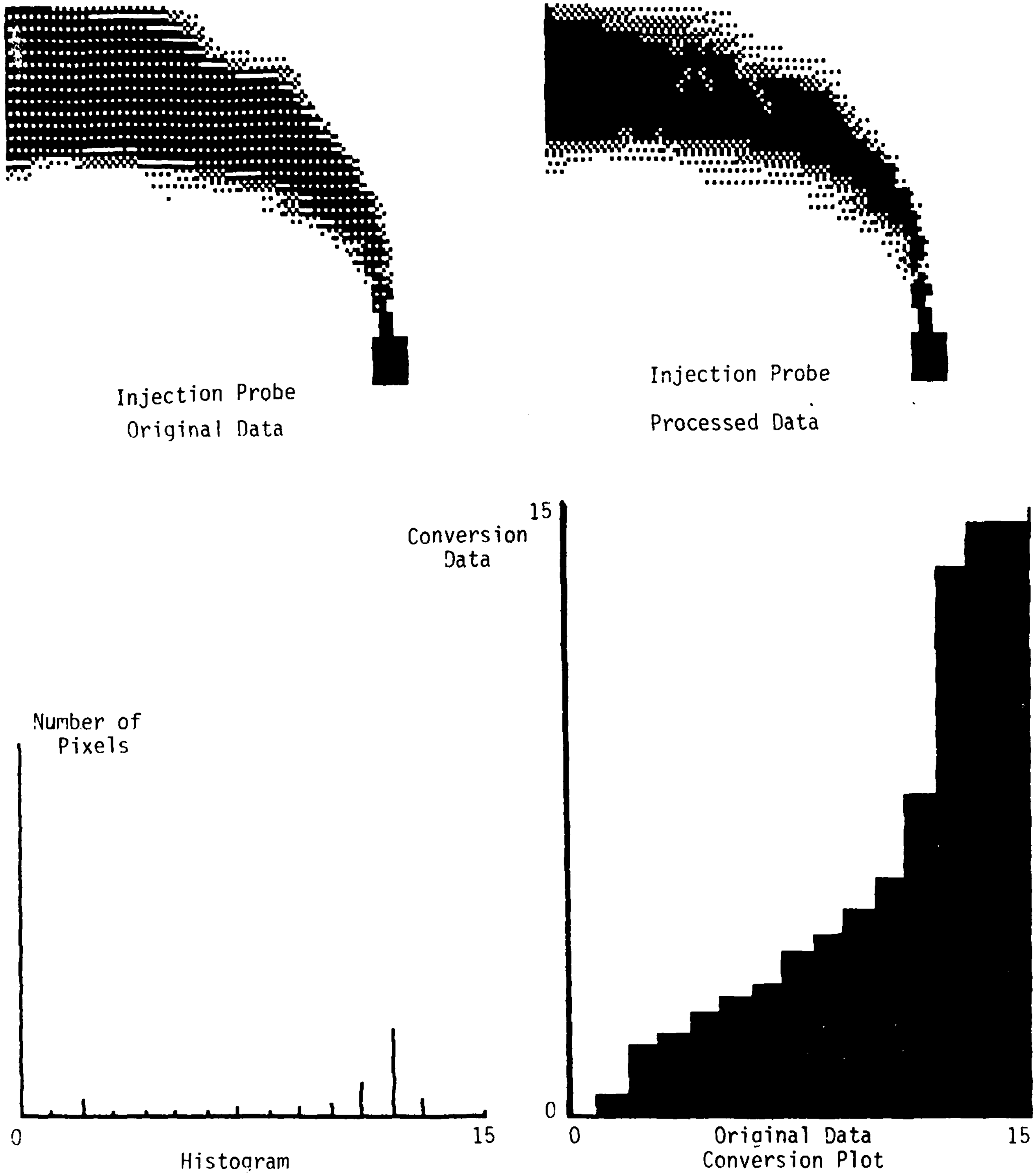
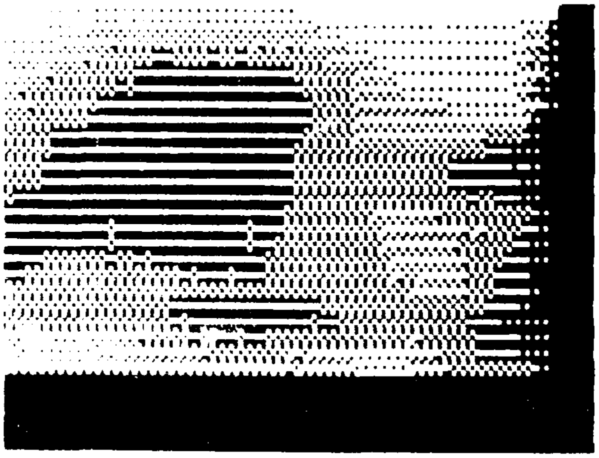
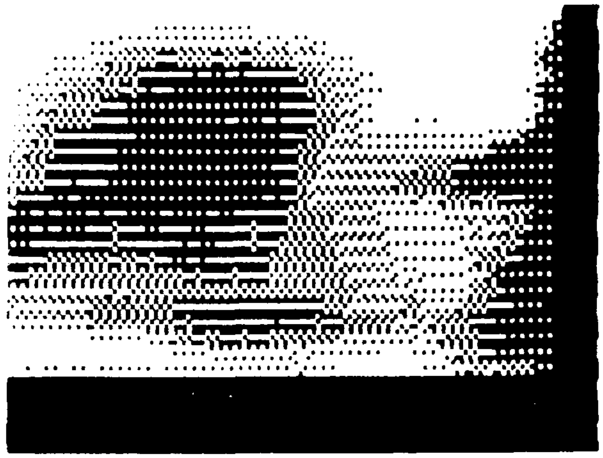


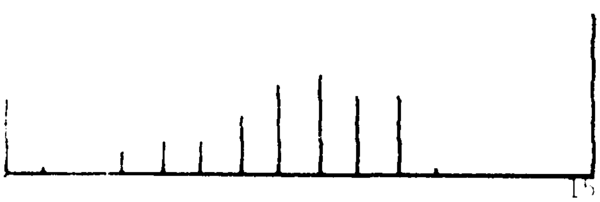
Figure 19. HISTOGRAM CORRECTION OF INJECTION PROBE IMAGE

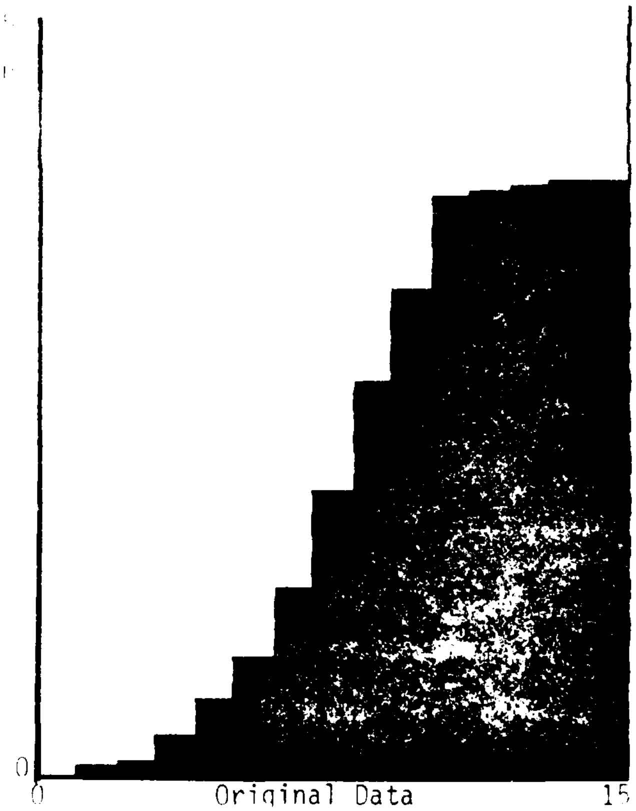




Wedge Model Flow

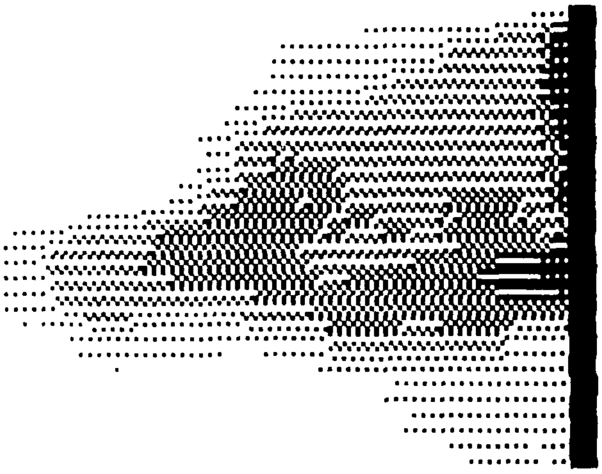
...rocessed Data





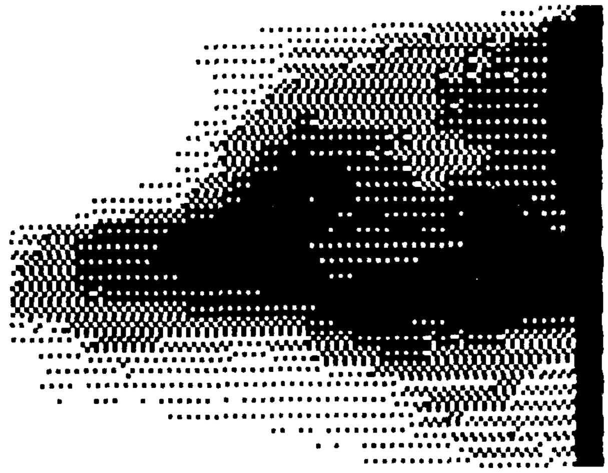
Original Data
Conversion Plot

[illegible] HISTOGRAM CORRECTION OF WEDGE MODEL FLOW IMAGE



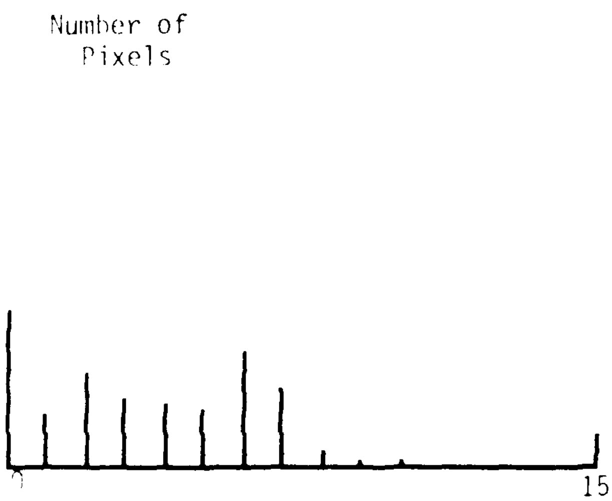
Centerbody Model Flow

Original Data

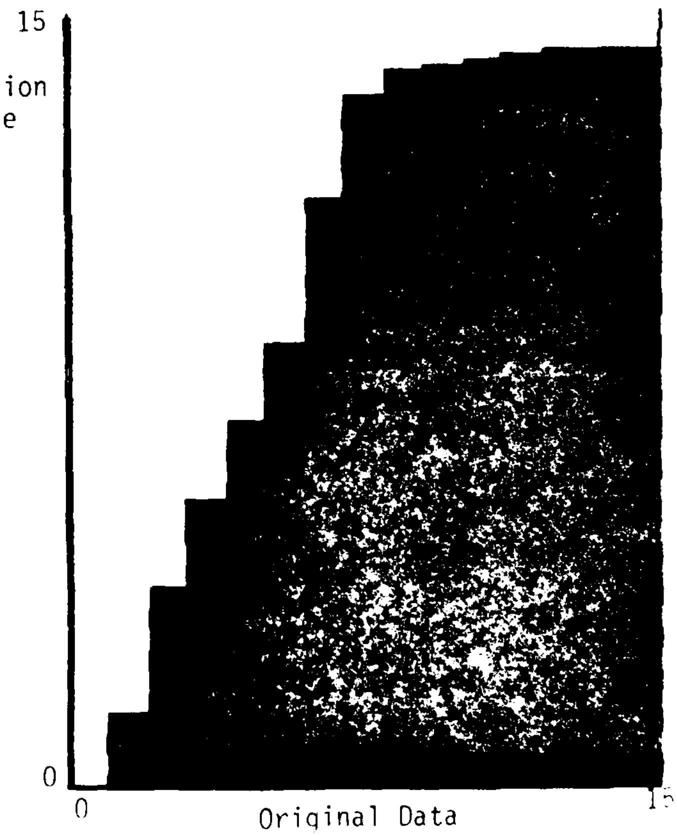


Centerbody Model Flow

Processed Data



Histogram



Original Data Conversion Plot

Figure 21. HISTOGRAM CORRECTION OF CENTERBODY MODEL F IMAGE

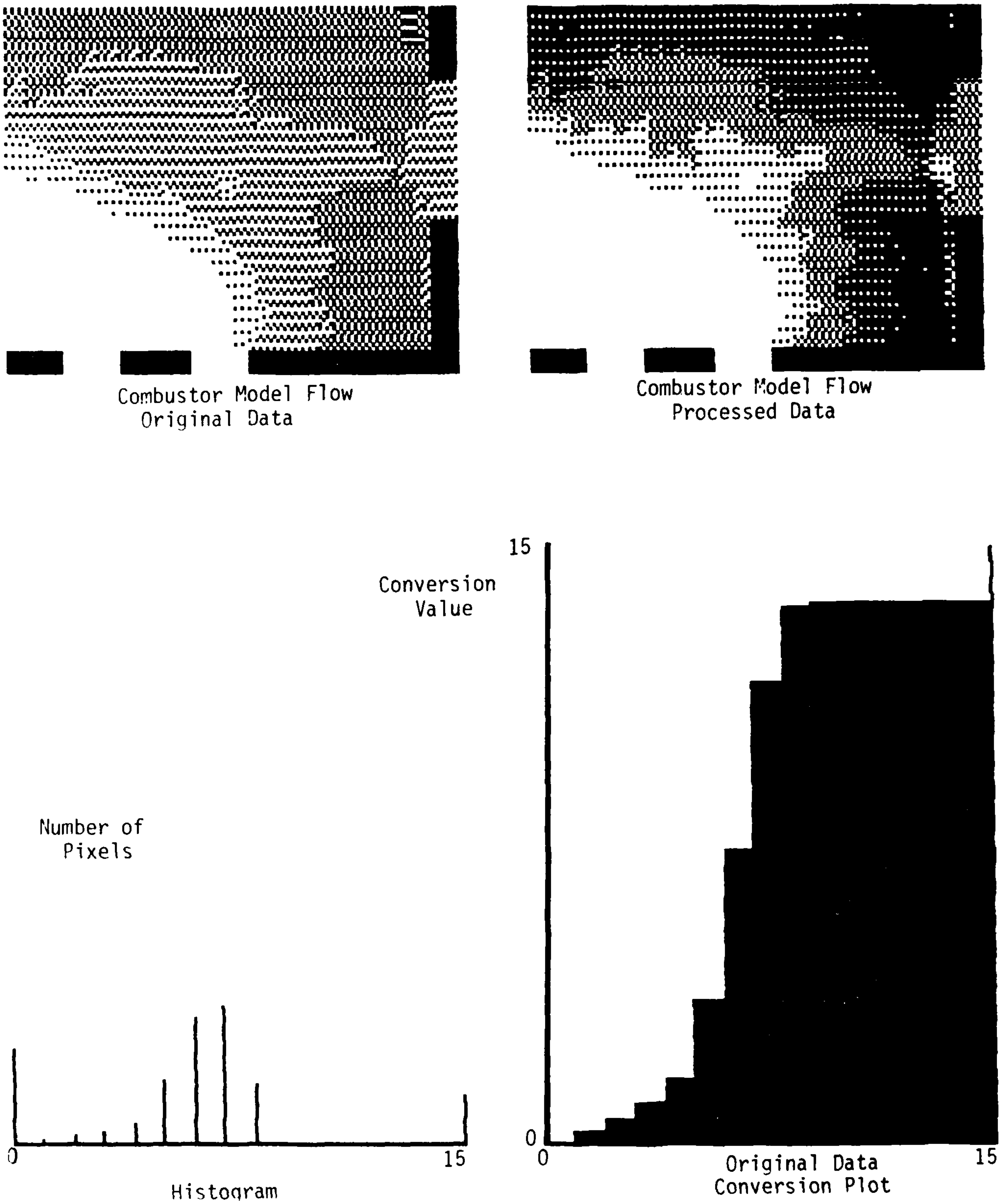
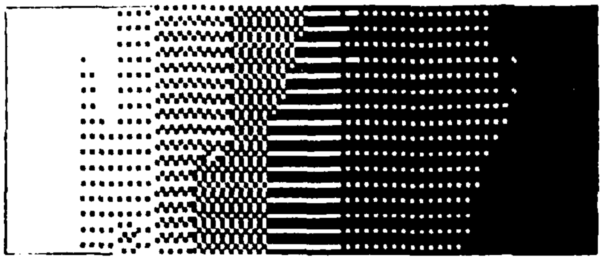
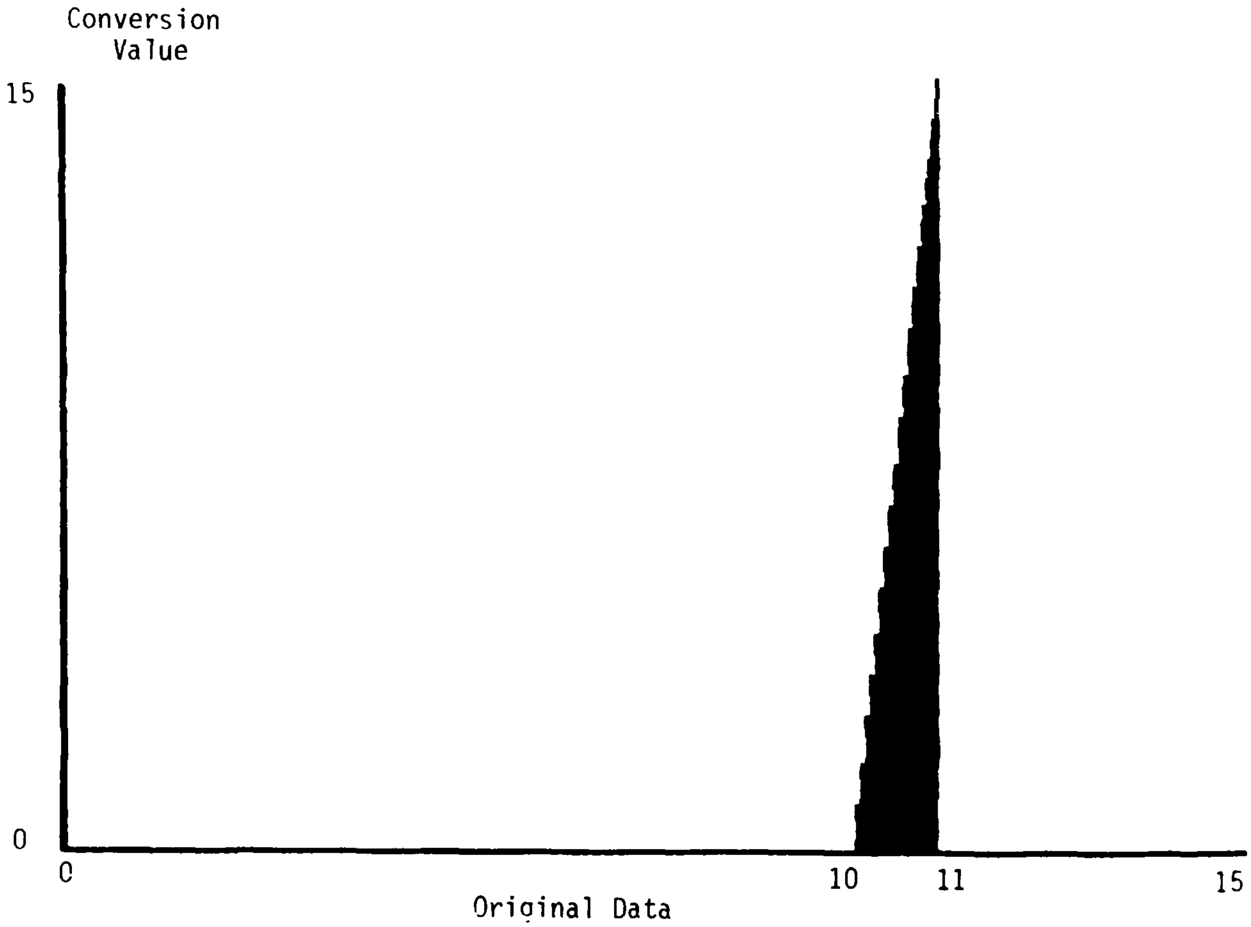


Figure 22. HISTOGRAM CORRECTION OF COMBUSTOR MODEL FLOW IMAGE



Gray-Level Scale
Original Data

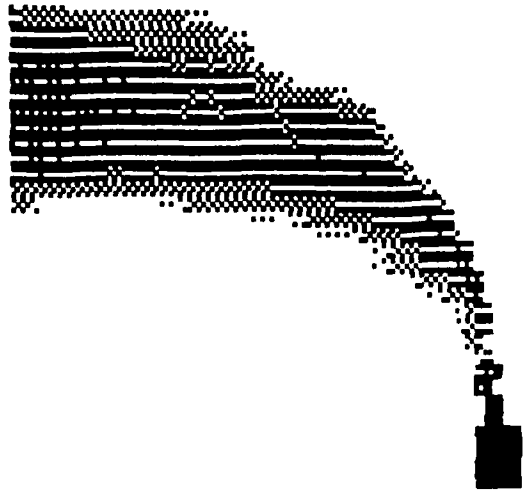
Gray-Level Scale
Processed Data



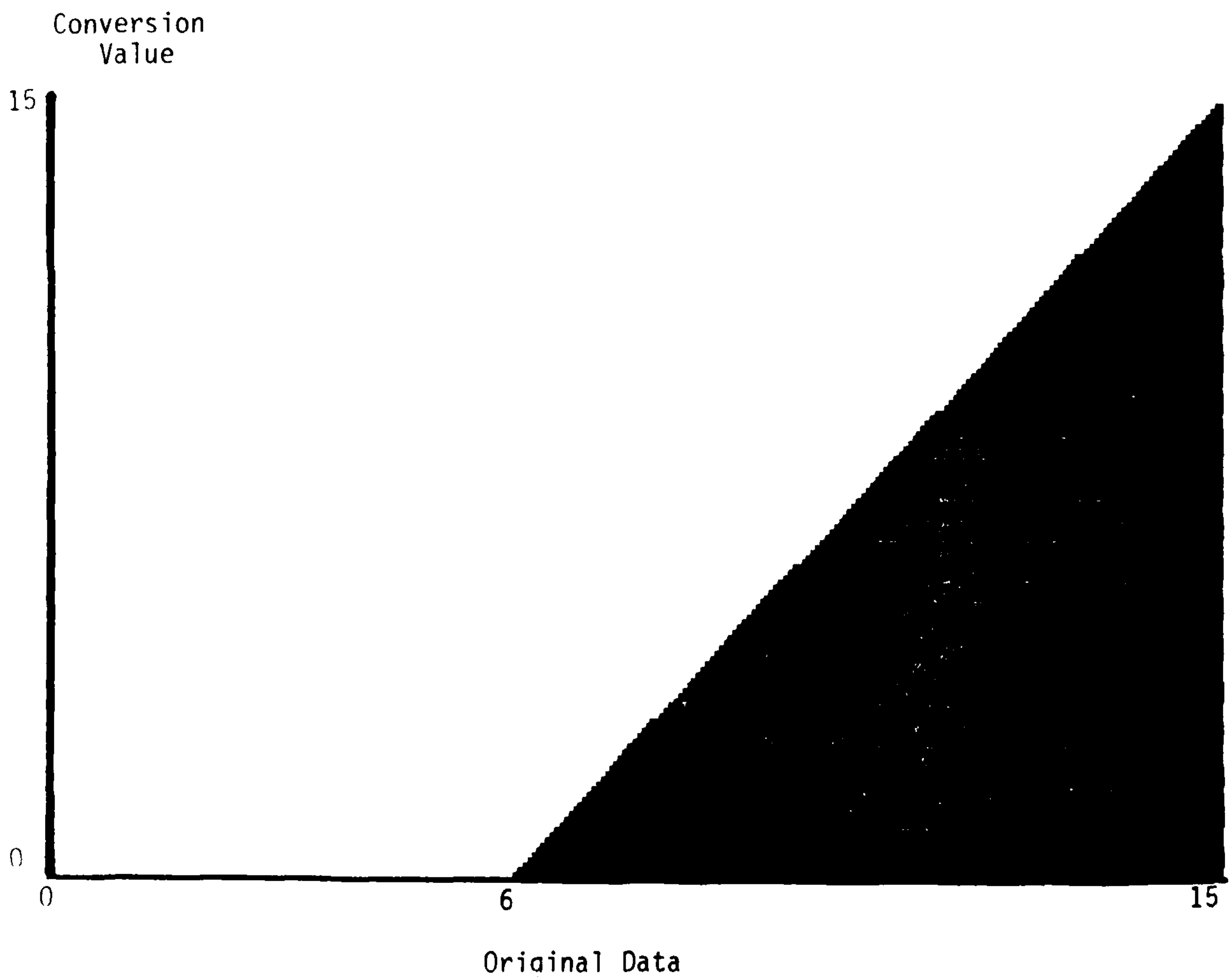
Segmentation Conversion Plot

Figure 23. SEGMENTATION CONVERSION OF GRAY-LEVEL SCALE IMAGE

Injection Probe
Original Data

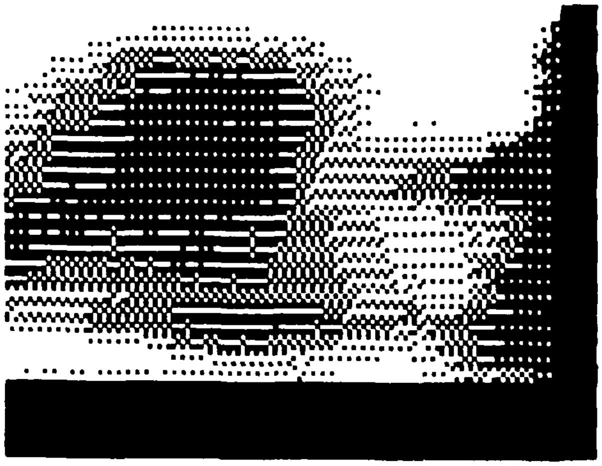


Injection Probe
Processed Data



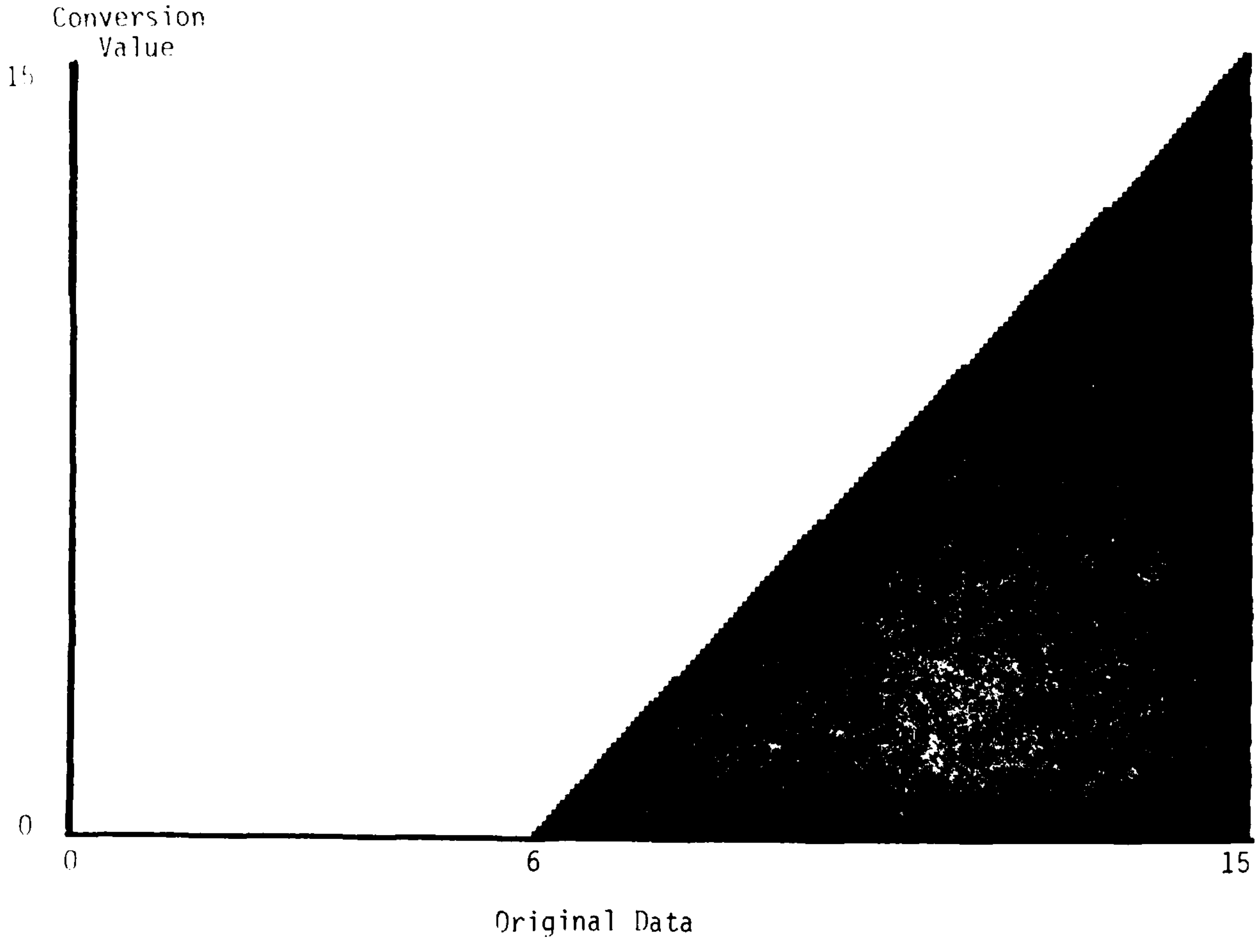
Segmentation Conversion Plot

Figure 24. SEGMENTATION CONVERSION OF INJECTION PROBE IMAGE



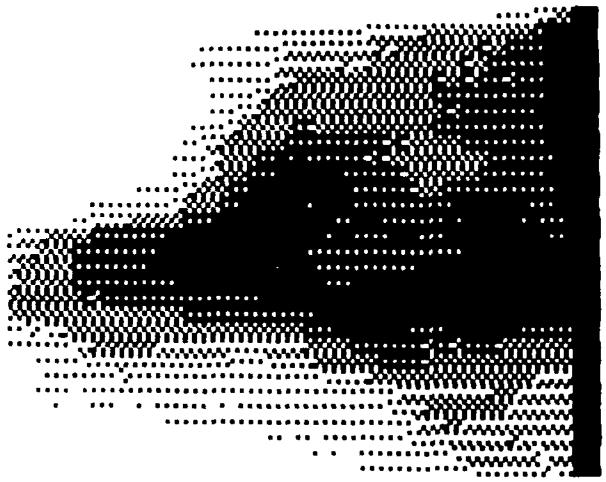
Wedge Model Flow
Original Data

Wedge Model Flow
Processed Data



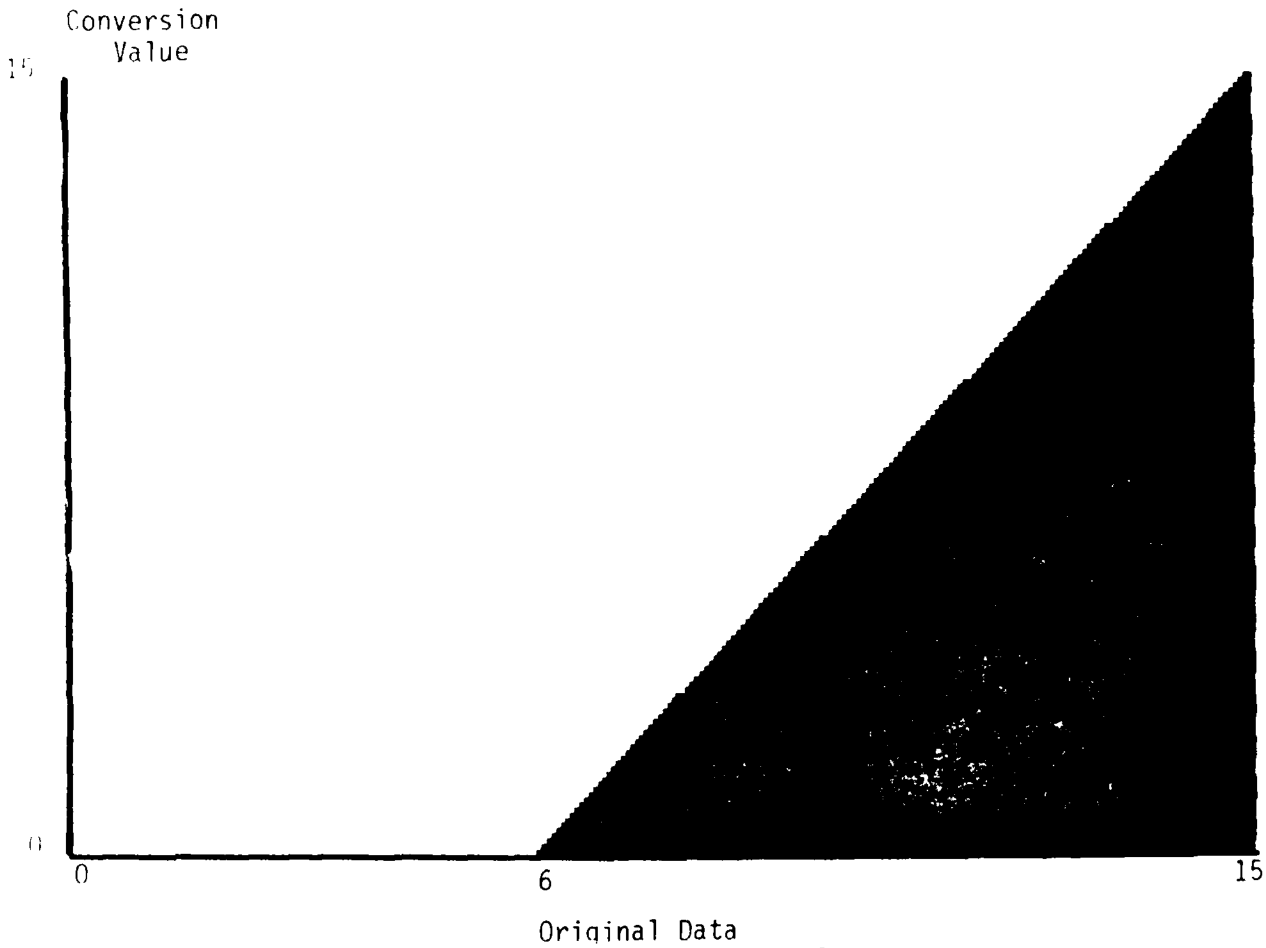
Segmentation Conversion of Wedge Model Flow Image

Figure 25. SEGMENTATION CONVERSION OF WEDGE MODEL FLOW IMAGE



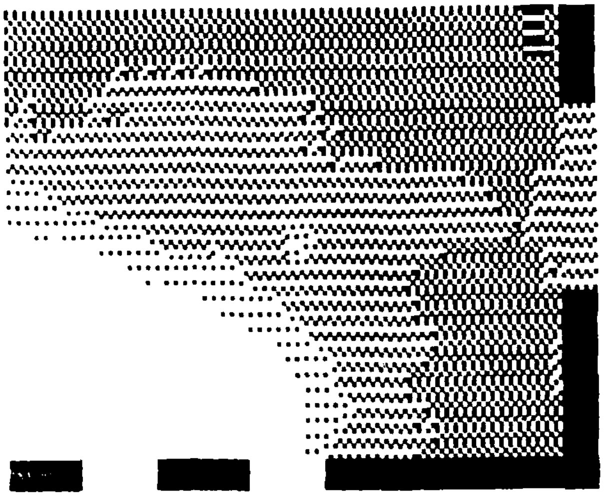
Centerbody Model Flow
Original Data

Centerbody Model Flow
Processed Data



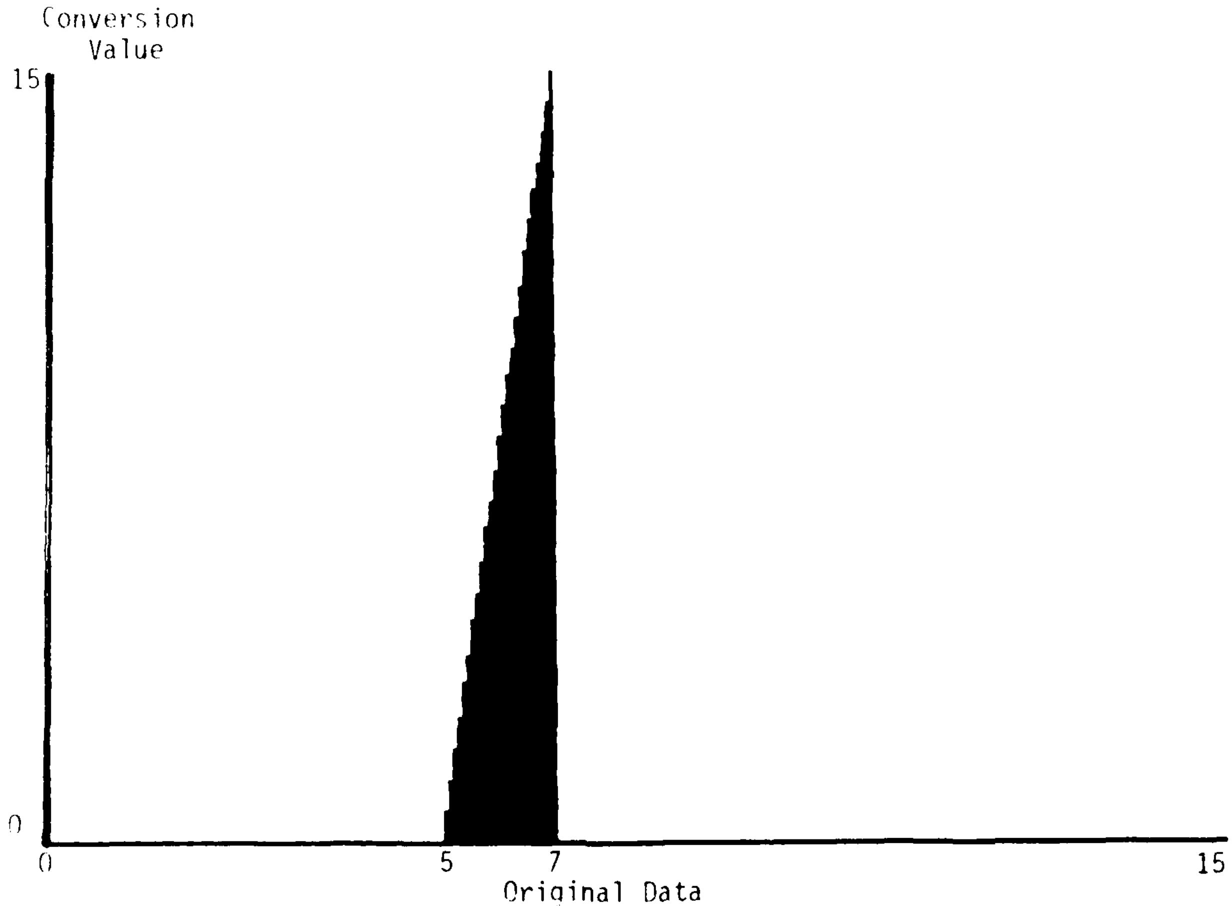
Segmentation Conversion Plot

Figure 26. SEGMENTATION CONVERSION OF CENTERBODY MODEL FLOW IMAGE



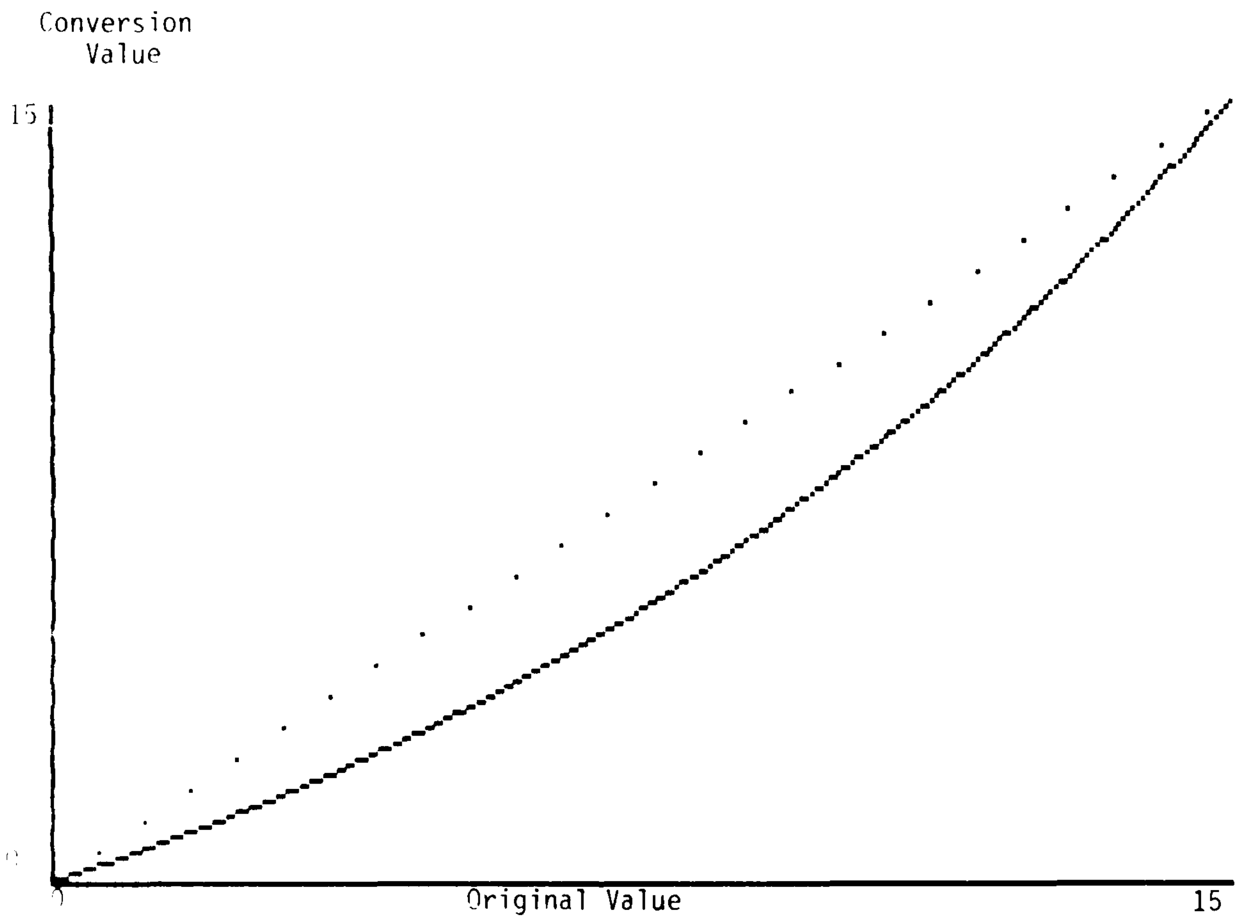
Combustor Model Flow
Original Data

Combustor Model Flow
Processed Data



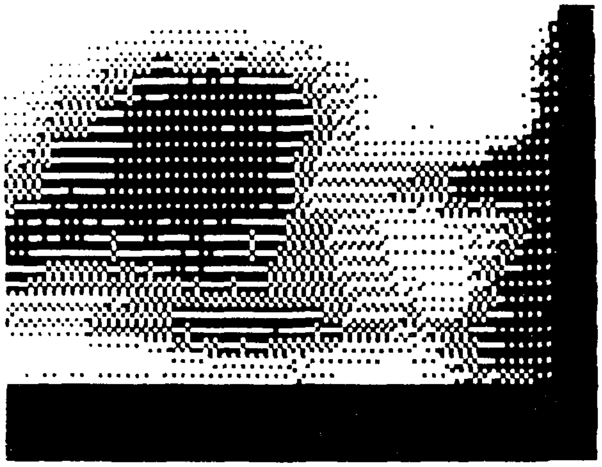
Segmentation Conversion Plot

Figure 27. SEGMENTATION CONVERSION OF COMBUSTOR MODEL FLOW IMAGE

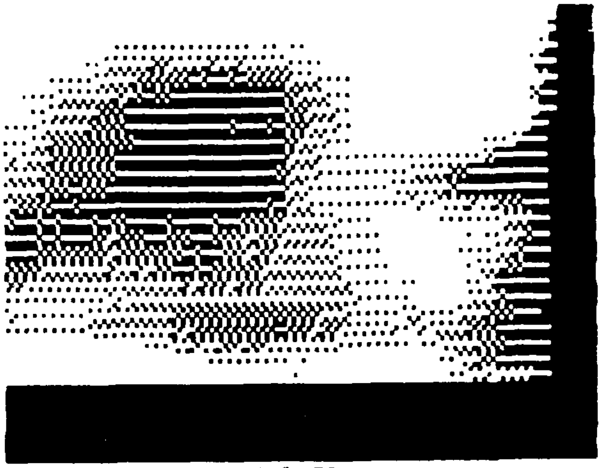


Logarithmic Conversion Plot

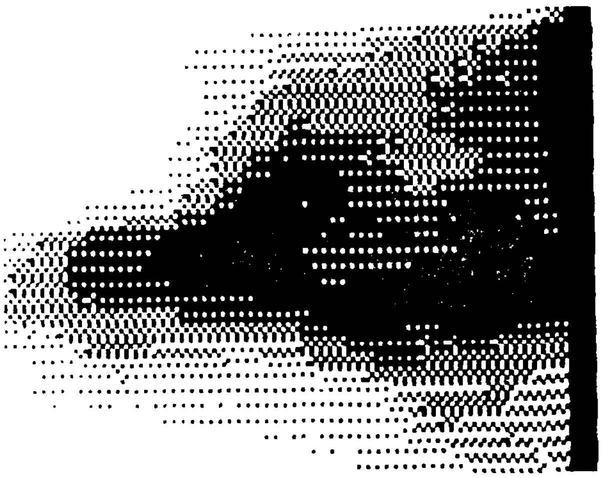
Figure 28. LOGRAITHMIC CONVERSION OF WEDGE AND CENTERBODY FLOW IMAGES



Wedge Model Flow
Original Data



Wedge Model Flow
Processed Data



Centerbody Model Flow
Original Data

Centerbody Model Flow
Processed Data

Figure 28. (concluded)

SECTION VI

CONCLUSIONS

From a series of turbulent dynamic fluid flow simulations, it has been demonstrated that quantitative and enhanced visual information can be obtained using a low-cost computer graphics system and image enhancement processing. The ability to capture, digitize, and color-map of flow visulaization data greatly improves the qualitative and quantitative value of visual data and makes analysis faster and easier. For situations where injected fluids or particles are being visually analyzed, the use of a computer graphics system can yield quantitative information regarding concentrations or distributions of the injected fluids or particles. When a fluid concentration is directly related to a visual gray-level value or color, that distribution can be quickly and easily determined by observation of a computer graphics image. In addition, the digital information is in a form that allows even more possibilities through computer processing.

The image enhancement processing of flow simulation visual data can provide more information regarding flow processes and can generate details that could not previously be determined. Image enhancement can be utilized to remove visual noise or unnecessary information; it can enhance information that may be difficult to visually detect; and can be used to obtain quantitative information regarding fluid concentrations within mixing zones. With new computer software routines, developed specifically for dynamic fluid analysis, image enhancement could become a valuable tool in the development of computer simulations of fluid dynamic processes.

This Phase I effort has demonstrated the capabilities of a low-cost computer graphics system and image enhancement processing to obtain both qualitative and quantitative information from flow simulation visual data. It would be beneficial to the Government and industry if efforts could continue into the Phase II effort to produce a prototype system that would be available as a commercial product. Such a product could be a very valuable engineering tool for use in fluid dynamic analysis, computer modelling, as a training aid, or possibly a chemical process or manufacturing control system. It is felt that efforts should be continued to develope a dynamic fluid analysis system.

LIST OF SYMBOLS

C	Dye Concentration by Volume
e	Natural Log
GL	Gray-Level

U.S. GPO 559-065

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